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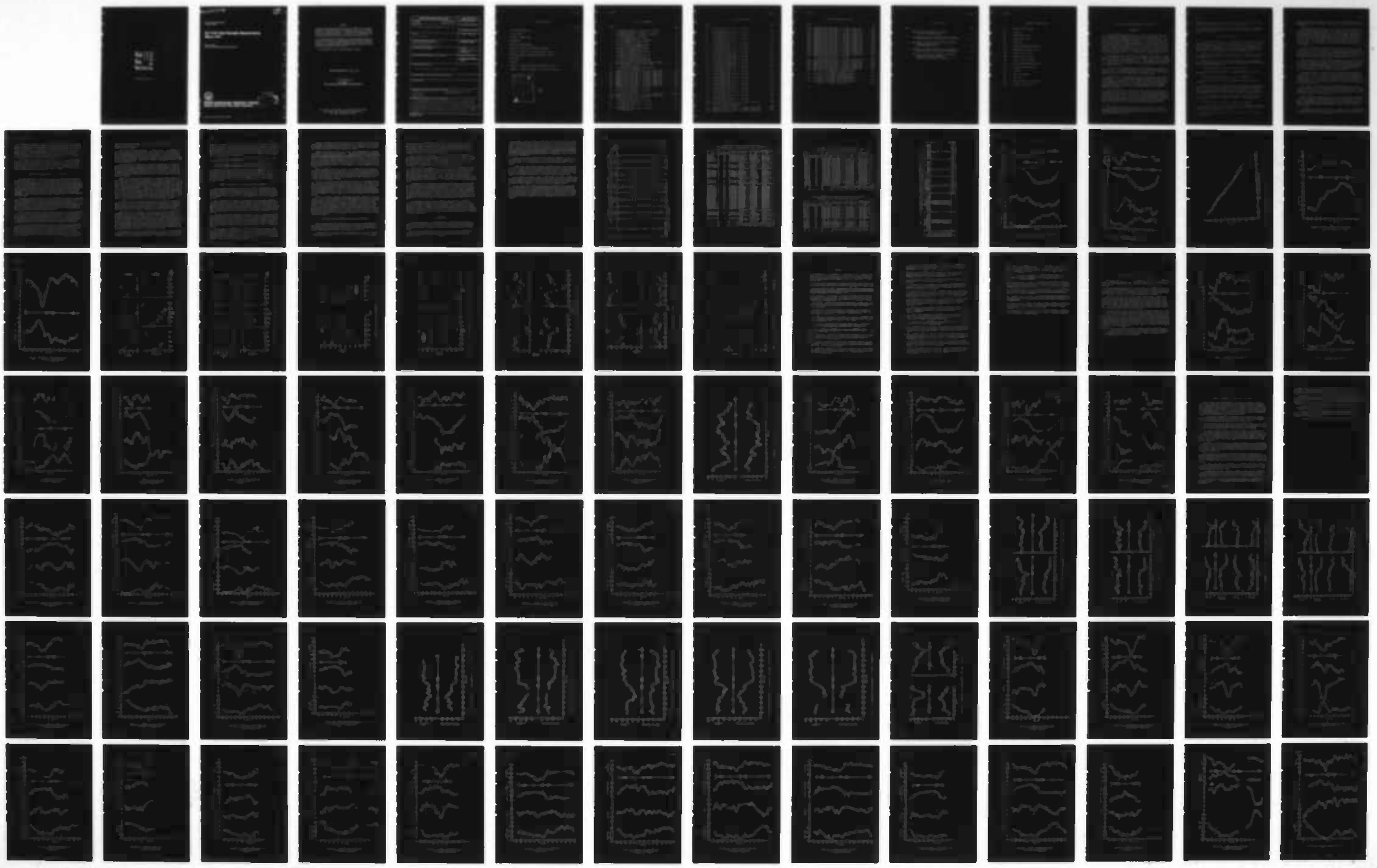

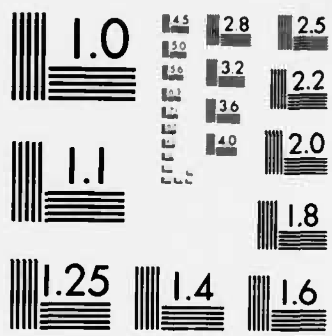

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ELF PVS Field Strength Measurements March 1977

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Approved for public release; distribution unlimited.

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Preface

This report was prepared under NUSC Project No. A59007, "ELF Propagation RDT &E" (U), Principal Investigator, P. R. Bannister (Code 3411). Navy Program Element No. 11401N and Project No. X0792-SB, Naval Electronic Systems Command Communications Systems Project Office, D. Dyson (Code PME 110), Program Manager ELF Communications, Dr. B. Kruger (Code PME 110-X1).

The analysis and write up of this report was performed while the author was occupying the Research Chair in Applied Physics at the Naval Postgraduate School, Monterey, CA. The author would especially like to thank Professors Otto Heinz and John Dyer and Dean Bill Tolles for recommending him to occupy this post and NAVSEA (Code 63R) for sponsoring the Chair.

The Technical Reviewer for this report was Raymond F. Ingram.

Reviewed and Approved: 3 February 1983

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From September 1976 to December 1978, extremely low frequency (ELF) field-strength and effective-noise measurements were taken aboard operational submarines. The results of measurements taken in Connecticut and aboard two submarines during March 1977 are discussed. Particular attention is focused on simultaneous Connecticut and North-Atlantic area measurements where nighttime propagation anomalies occurred 2 to 4 hr apart. A prime candidate for the cause of these anomalies is a moving nocturnal sporadic E-layer.

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GLOSSARY OF ABBREVIATIONS

ELF	Extremely low frequency
EW	East-west
GMT	Greenwich Mean Time
MSK	Minimum shift keying
NS	North-south
NUSC	Naval Underwater Systems Center
PVS	Propagation validation system
SNR	Signal-to-noise ratio
SRTP	Sunrise transition period
SSTP	Sunset transition period
STIU	Signal timing and interface unit
TEM	Transverse electromagnetic
TTY	Teletype
VLF	Very low frequency
WE	West-east
WKB	Wentzel, Kramers, and Brillouin
WTF	Wisconsin Test Facility

ELF PVS FIELD STRENGTH MEASUREMENTS, MARCH 1977

INTRODUCTION

The ELF* propagation validation system (PVS) is composed of the U. S. Navy's extremely low frequency (ELF) Wisconsin Test Facility (WTF) and ELF receivers (AN/BSR-1) installed on submarines and at certain land sites. The WTF is located in the Chequamegon National Forest in north-central Wisconsin, about 8 km south of the village of Clam Lake. It consists of two 22.5 km antennas; one antenna is located approximately in the north-south (NS) direction and one is located approximately in the east-west (EW) direction. Each antenna is grounded at both ends. At 76 Hz, the electrical axis of the NS antenna is 14 deg east of north, while the electrical axis of the EW antenna is 114 deg east of north.[1] The WTF antenna array can be steered electrically toward any particular location. Its radiated power is approximately 1 W.

The AN/BSR-1 receiver is composed of an AN/UYK-20 minicomputer, a signal timing and interface unit (STIU), a rubidium frequency time standard, two magnetic-tape recorders, and a preamplifier. The message output is on a teletype (TTY), which is used to control the receiver. The submarine receiving antenna is a buoyant cable 1.6 cm in diameter with electrodes spaced 300 m apart on a 580 m transmission line.

The system uses minimum shift keying (MSK) modulation with a center frequency of 76 Hz. The signalling scheme uses block orthogonal coding to make maximum use of the limited transmitter power available. This scheme provides the most efficient use of the transmitter for short messages.

During March 1977, one submarine involved in testing was located in the North-Atlantic area at a range of approximately 4 Mm from WTF, while another test submarine was located near Hawaii. Signal-strength (both amplitude and relative phase), effective-noise, and signal-to-noise ratio (SNR) data were recorded automatically by each test submarine whenever the ELF receiving antenna was streamed, though no special operational posture was adopted to provide ELF reception.

In the submarine data, the depth and orientation of the submarine are automatically accounted for by the receiver. The submarine data analyzed in this report have been taken at essentially constant depth and orientation for considerable periods of time. We also have a substantial amount of unreduced (as far as signal amplitude and phase are concerned) submarine data where the speed, depth, and orientation of the submarine were varying considerably. These particular data are not too useful for obtaining accurate signal

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*ELF (formerly called SANGUINE/SEAFARER) is an arbitrary designation applied to ongoing extremely low frequency research by the U. S. Navy. The term designates work directed toward the implementation of an ELF shore-to-ship radio communication system.

amplitude and phase information. However, they are very useful for obtaining information on messages received during submarine maneuvers.

In this report, we will discuss the results of these March 1977 submarine field-strength measurements and will compare them with simultaneous measurements taken in Connecticut.

MARCH 1977 AVERAGE RESULTS

During this time period, data were obtained on 17 days from the submarine in the North-Atlantic area and from the Connecticut site on 29 days. The daily plots of signal strength, effective noise, and SNR versus Greenwich Mean Time (GMT) are presented in appendix A for submarine data and in appendix B for Connecticut data. Unfortunately, only a very limited amount of data (approximately 3 days) were obtained from the submarine in the Hawaii area.

The WTF antenna phasing (ψ) was 201 deg from 1 to 5 March, 111 deg on 6 and 7 March, and 291 deg during the rest of the month. The WTF transmitting frequency was 76 ±4 Hz.

Presented in table 1* are the March 1977 North-Atlantic-area submarine daily field-strength averages. These data are broken up into four time periods, which should be representative of

1. Nighttime propagation conditions (~0100 to 0830 GMT),

2. Sunrise transition period (SRTP) propagation conditions (~0830 to 1300 GMT),

3. Daytime propagation conditions (~1300 to 2030 GMT), and

4. Sunset transition period (SSTP) propagation conditions (~2030 to 0100 GMT).

Referring to table 1, we see that there is a considerable day-to-day variation in the received field strengths (both in amplitude and relative phase). That is, the average field strength sometimes changes by 2 to 4 dB from one day to the next, while the average relative phase changes by 15 to 30 deg. This phenomenon is typical of ELF propagation on northern-latitude paths.[2,3]

The 6 through 27 March average field-strength, relative-phase, SNR, and effective-noise† values are presented in figure 1,†† while the 1 through 5

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*All tables are placed together at the end of this report.

†The effective-noise spectrum level (in dBH = dBA/m·$\sqrt{1\ \text{Hz}}$) is defined as the spectrum level of ELF noise at the signal frequency divided by the improvement (in SNR) using nonlinear processing.[4]

††Figures are placed together at the end of this report, or in the applicable appendix.

March average data are presented in figure 2. For comparison purposes, the 1 through 5 March data (ψ = 201 deg) are normalized to a WTF antenna phasing of ψ = 291 deg.

Referring to table 1 and figures 1 and 2, we see that the average relative-phase plots for the two different time periods were very similar, as were the daytime signal-strength and SNR values. However, during nighttime and transition-period propagation conditions, the field-strength (amplitude) and SNR average values were considerably different. For example, from 0300 to 0400 GMT, the 1 to 5 March average nighttime field strength and SNR were 4 to 6 dB lower than the 6 to 27 March values. On the other hand, from 0700 to 0800 GMT, the 1 to 5 March average nighttime field strengths and SNR's were 2 to 3 dB higher. The 1 to 5 March data will be discussed in more detail later in this report.

A plot of the March 1977 North-Atlantic-area SNR distribution (N = 507 30-min samples) is presented in figure 3. From this curve, we see that the predetection (in a 1-Hz bandwidth) SNR <u>at optimum heading</u> was greater than -9 dB 50 percent of the time and greater than -13 dB 90 percent of the time. The postdetection SNR (after a 30-min integration time) was greater than 23.5 dB 50 percent of the time and greater than 19.5 dB 90 percent of the time.

During January 1977, field-strength measurements were taken in Connecticut and aboard three submarines located in the North-Atlantic/Norwegian-Sea area. The daytime and nighttime attenuation rates inferred from these measurements were 1.25 and 0.9 dB/Mm, respectively, while the excitation factors were -1.0 dB during the day and -3.8 dB at night.[5] These values are consistent with previous measurements taken over similar propagation paths.[6,7]

Referring to table 1, we see that the average March North-Atlantic-area (~4 Mm from WTF) daytime, transition period, and nighttime measured field strengths were -151.0, -151.3, and -152.1 dBA/m, respectively. Based on the abovementioned values of attenuation rate and excitation factor, the predicted field strengths at a range of 4 Mm are -150.8, -151.5, and -152.2 dBA/m, respectively, which are in excellent agreement with the measured North-Atlantic-area field strengths.

The average of a very limited amount (approximately 3 days) of field-strength and effective-noise Hawaii-area data is presented in figure 4. From this curve, we see that the diurnal field-strength variation was ~4 dB, while the effective-noise variation was ~12 dB. This large diurnal effective-noise variation is typical of Pacific-area noise.[8]

From our previous measurements,[6,7] we have observed that during daytime-propagation conditions, the attenuation rate in the EW direction is approximately 0.3 dB/Mm greater than that in the west-east (WE) direction at 75 Hz. This is in agreement with the theoretical work of Galejs,[9] who showed that below 100 Hz the attenuation-rate differences between EW and WE directions will be slight.

The daytime and nighttime attenuation rates inferred from the March/April 1971 Utah/Hawaii measurements were 1.5 and 0.9 dB/Mm, respectively, while the excitation factors were +0.3 dB during the day and -3.3 dB at night.[6,7,10]

Based on an (unpublished) analysis of all the Pacific-area PVS measurements, it appears that the attenuation rates and excitation factors inferred from the March/April 1971 Utah/Hawaii measurements also apply to the general Pacific area, with the exception of the nighttime excitation factor. This appears to be -2.1 dB (1.2 dB higher). It is interesting to note that the only other long-path Pacific-area ELF measurements (i.e., Alaska/Saipan, May 1972[6,7]) resulted in a 75-Hz nighttime excitation factor of -4.5 dB, which was 1.2 dB lower than that measured during March/April 1971.

The average March 1977 Hawaii-area daytime, transition period, and nighttime measured field strengths were -156.9, -155.9, and -155.3 dBA/m, respectively. Based on the abovementioned values of attenuation rate (1.5 and 0.9 dB/Mm) and excitation factor (+0.3 and -2.1 dB), the predicted Hawaii-area field strengths are -157.0, -156.0, and -155.1 dBA/m, respectively, which are in excellent agreement with the measured field strengths.

LOCALIZED ELF NOCTURNAL-PROPAGATION ANOMALIES

The most important ELF earth-ionosphere waveguide propagation parameters are the attenuation rate, phase velocity, and excitation factor. We have shown[7] that, on the average, the ELF attenuation rate is directly proportional to the excitation factor. The fact that these two quantities are proportional is not really surprising since, for both single-layer and exponentially varying ionospheric-conductivity models, both quantities are inversely proportional to the ionospheric reflection height.[7,11] What this suggests is that, on the average, if the nighttime (or daytime) excitation factor is increased (or decreased), then the nighttime (or daytime) attenuation rate is also increased (or decreased).

On several occasions during the past decade, the 40 to 80 Hz ELF nighttime field strength measured at sites in the northeastern United States (i.e., Connecticut and Maryland) has displayed rapid decreases of from 4 to 8 dB in several hours.[12-18] These severe nighttime disturbances sometimes occur during the several days following magnetic storms when similar but less-pronounced behavior is found to coincide with phase disturbances on very low frequency (VLF) paths across the northern United States.[19]

We have shown[13,16] that the Connecticut nighttime field-strength amplitude was usually at a minimum between 0600 and 0800 GMT, whereas the nighttime relative phase was at a maximum approximately 1 hr earlier. The time of the lowest nighttime field strengths coincides with the farthest-south displacement of the auroral oval and, presumably, indicates the time at which energetic electrons would reach their southernmost point in the middle latitudes.

It has been postulated[19-23] that levels of the D-region controlling ELF propagation in the earth-ionosphere waveguide are strongly influenced by energetic-electron precipitation. Recently reported measurements[24,25] are consistent with the theoretical results of Spjeldvik and Thorne[22,23] regarding ionization caused by precipitation of energetic electrons during the recovery phase of magnetic storms. Because energetic-particle precipitation into the D-region tends to increase ionization, making the ionosphere more "daylike" by lowering the effective reflecting height and improving excitation, the observed nighttime field-strength decreases are in the opposite sense to that which would have been expected.

Imhof et al.,[26] from coordinated satellite and ELF field-strength measurements, have found that direct particle precipitation into the atmosphere can cause ELF transmission anomalies. In these anomalies, the signal strengths may be either attenuated or enhanced, depending on the spatial extent and location of the ionization. The effect appears to be due primarily to changes in the excitation factor. Other factors, such as standing-wave effects, may also be of importance.[19]

Several authors[27,28] have made calculations regarding the influence of a sporadic E-layer that encompasses the nighttime propagation path. They have shown that the presence of nocturnal sporadic E produced marked maxima and minima in the propagation characteristics of ELF radio waves. One physical explanation for the enhanced absorption could be in terms of an attenuation resonance between waves reflected from normal E-region heights and from the sporadic E-region.

Pappert[29] and Pappert and Shockey[30] have investigated the effects of a more realistically sized patch of sporadic E on nighttime propagation in the lower ELF band. Their results indicate that a sporadic E patch 1 by 1 Mm that causes phase shifts and attenuation-rate enhancements consistent with full-wave model evaluations can account for the 6 to 8 dB fades observed in the Connecticut and Maryland measurements. Patches 1 by 0.5 Mm can account for more commonly observed fades in the 3 to 4 dB range. Of the cases examined, deepest fades occur when the disturbance falls over the receiver and the depth of the fades in those instances changes very little with the location of the disturbance along the great-circle path connecting transmitter and receiver. In other words, a receiver moving beneath a traveling, but otherwise invariant, ionospheric disturbance would experience a very nearly constant fade.[29]

It should be noted that actual measurements of sporadic-E conditions have not been made at the receiving sites when WTF was transmitting. Attempts to explain the observed ELF-signal fades in terms of absorption due to sporadic-E conditions can, therefore, not be conclusive, but the theoretical efforts in this area point out the potential influences of sporadic E on ELF propagation.

Field and Joiner[31] employed an integral-equation approach for analyzing propagation in the earth-ionosphere waveguide where conditions change over distances comparable with a Fresnel zone. They derived an expression for the relative errors introduced by neglecting transverse ionospheric gradients over the path and found that full-wave methods must be applied when the effective width of a localized disturbance is less than two-thirds of the width of the first Fresnel zone. They also concluded that the Wentzel, Kramers, and Brillouin (WKB) approximation significantly overestimates the propagation anomaly when the disturbance is centered near the propagation path and underestimates the anomaly when the disturbance is centered far off-path.

Subsequently, Field and Joiner[32] extended their analysis by analyzing ELF propagation for both widespread and bounded inhomogeneities. Their solutions showed that such a disturbance behaves like a cylindrical lens filling a narrow aperture. Lateral diffraction, focusing, and reflection can cause the transverse electromagnetic (TEM) mode to exhibit a transverse pattern of maxima and minima beyond the disturbance and a standing-wave pattern in front of it. The focusing and diffraction diminish when the transverse dimension of the disturbance approaches the width of the first Fresnel zone, typically, several megameters. Their analysis shows that reflection from widespread inhomogeneities can be important in two situations:

1. For great-circle propagation paths that are nearly tangential to the boundary of the disturbed polar cap, and

2. When the TEM mode is obliquely incident on the day/night terminator, in which case a phenomenon analogous to internal reflection can occur.

In the next section, we will present additional examples of localized ELF nighttime field-strength anomalies and show that these variations are not restricted to northeastern United States measurement locations. Particular attention will be focused on simultaneous Connecticut and North-Atlantic-area measurements where nighttime propagation anomalies occurred 2 to 4 hr apart. A prime candidate for the cause of these anomalies is a moving nocturnal sporadic E-layer.

MARCH 1977 EXAMPLES OF LOCALIZED NIGHTTIME ANOMALIES

On many measurement dates during the fall of 1976, the nighttime field-strength (amplitude) measurements were found to be at a minimum from 0600 to 0800 GMT. Conversely, the nighttime relative phase was found to be at a maximum approximately 1 hr earlier.[13,16] This phenomenon is not just restricted to the fall season (in particular to the Halloween period), as illustrated in figure 5.

On 22 February 1977 (figure 5), the nighttime field-strength amplitude steadily decreased for a total of 6 dB from 0100 to 0800 GMT and, then, steadily increased for a total of 6.5 dB from 0800 to 1200 GMT. Meanwhile, the nighttime relative phase increased a total of 25 deg from 0300 to 0700 GMT and, then, decreased a total of 35 deg from 0700 to 0930 GMT. (It should be noted that the postdetection SNR measured during the 0100-1200 GMT period was 25 to 30 dB.)

The 0300 to 0700 GMT nighttime relative-phase increase was about the same phase change usually associated with the sunrise-sunset terminators crossing the WTF-Connecticut path. Intuitively, we would assume an increase in phase would be due to an increase in the reflecting height and, thus, a decrease in the electron density near the normal reflection height (~75 km[7]). However, this would require an unrealistic nighttime reflection height of approximately 150 km.

A more plausible explanation is that the field-strength amplitude reduction (accompanied by a relative-phase increase) is due to the presence of a nocturnal sporadic E-layer. This is in agreement with the results of Pappert and Shockey,[30] who showed that phase increases of ~30 deg are possible in the neighborhood of the attenuation-rate resonance caused by waves reflected from normal E-region heights and from the sporadic E-region.

During the magnetically quiet period of early March 1977, field-strength measurements were taken in Connecticut and aboard a submarine located in the North Atlantic (approximately 4 Mm from WTF). Many nighttime field-strength variations were observed at both receiving locations.

Figure 6 shows plots of the 1 to 3 March 1977 nighttime field strengths measured at both locations, against GMT. Note that the Connecticut and submarine field-strength-versus-GMT plots are displaced by 4 hr. During these three nights, the observed peak-to-trough variations were 6 to 8 dB in Connecticut and 7 to 11 dB at the submarine receiving location. Because (1) the late-February/early-March period was magnetically quiet and (2) the decreases in nighttime field strengths occurred at different times at the two receiving sites, a prime candidate for the cause of these anomalies is a moving nocturnal sporadic E-layer.

Shown in figure 7 are the 4 to 6 March 1977 nighttime field strengths measured at the two receiving locations. The field-strength-versus-GMT plots (which are very similar at both receiving locations) are displaced by 4 hr on 4 and 5 March and by 2 hr on 6 March. The peak-to-trough variations are 4 to 7 dB at both locations. Again, a probable cause of these variations is a moving nocturnal sporadic E-layer.

Figure 8 shows plots of the 10 and 11 March 1977 field strengths versus GMT. For these plots, the time displacement is only 2 hr. On 10 March, the nighttime peak-to-trough variation was ~6 dB in Connecticut and ~8 dB at the submarine receiving location. During 11 March, the Connecticut nighttime field strength decreased ~3 dB over a 6-hr period, while the submarine field strength gradually decreased ~6 dB. These variations were probably caused by particle-bombardment effects during the 9 March 1977 magnetic-storm recovery period.

Another interesting anomalous nighttime-propagation condition is shown in figure 9. On 17 March, from 0100 to 0600 GMT, both the Connecticut and submarine nighttime field strengths were 2 to 3 dB lower than on the previous nights, which is indicative of a propagation anomaly along the whole path, or at WTF. On both 26 January and 17 March, from 0630 to 0800 GMT (i.e., the last 1-1/2 hr of the nighttime period), the field strength in Connecticut decreased by only approximately 1 dB. However, the field strength at the submarine location decreased by ~7 dB (on 17 March) and by ~9 dB (on 26 January). These 0630 to 0800 field-strength degradations must have been caused by local ionospheric anomalies.

SNR BEHAVIOR DURING ANOMALOUS-PROPAGATION CONDITIONS

On many measurement days during the past few years, we have noticed at the Connecticut site that the ELF nighttime field-strength amplitudes minimized between 0400 and 0800 GMT. Intuitively, one would think that when the signal level decreases, the noise level would also decrease.

A comparison of the field-strength, atmospheric-noise, and SNR behavior was made during 34 nights from 1973 to 1975. During the comparison period, field strength varied considerably during the nighttime measurement period, or from night-to-night, as is presented in table 2. As shown in table 2, large decreases in signal strength were not usually accompanied by large decreases in atmospheric-noise levels. The average signal decrease was approximately 4.5 dB, and the average noise decrease was approximately 0 dB, resulting in an average SNR decrease of approximately 4.5 dB.

Table 3 provides a comparison of nighttime field-strength, effective atmospheric-noise, and SNR behavior during 17 nights of 1976. Note that large decreases in signal strength were not accompanied by large decreases in effective atmospheric-noise levels. The average signal decrease was approximately 3.7 dB and the average effective-noise decrease was approximately 0.6 dB, resulting in an average SNR decrease of approximately 3 dB.

Table 4 presents a comparison of the nighttime field strength in Connecticut, the effective atmospheric noise, and the SNR behavior during March 1977. This comparison is illustrated in figures 10 and 11. Again, we find that large decreases in signal strength are not accompanied by large decreases in effective atmospheric-noise levels. The average signal decrease during 12 days in March was approximately 5.3 dB and the average effective-noise decrease was approximately 1.3 dB, resulting in an average SNR decrease of approximately 4 dB.

A comparison of the minimum and maximum nighttime SNR's measured aboard the North-Atlantic-area submarine during March 1977 is presented in table 5, and the relative SNR's are plotted versus GMT for six specific days in figure 12. We see here that large decreases in signal strength are not accompanied by large decreases in effective atmospheric-noise levels, as we also observed in the Connecticut measurements. The average signal decrease during 11 days in March was approximately 6.8 dB and the average effective-noise decrease was approximately 0 dB, resulting in an average SNR decrease of approximately 6.8 dB.

This comparison of ELF signal-strength, atmospheric-noise, and SNR behavior during 67 low-amplitude field-strength nights has shown that large decreases in signal strength are not accompanied by large decreases in atmospheric-noise levels. Probably, ELF nighttime signal decreases are not accompanied by effective-noise decreases because the signal path is a point-to-point path (i.e., highly directional), while the atmospheric-noise path is essentially a nondirectional path.

CONCLUSIONS

The average measured field strengths taken aboard two submarines (one located in the North-Atlantic area and one located near Hawaii) during March 1977 are in excellent agreement with previous ELF measurements over similar paths.

On several occasions during the past few years, the ELF nighttime field strength measured in the northeastern United States has displayed rapid decreases of from 4 to 8 dB in several hours. The time of the lowest nighttime field strengths (0600-0800 GMT) coincides with the farthest-south displacement of the auroral oval and, presumably, indicates the time at which precipitated energetic electrons would reach their southernmost point in the middle latitudes. Therefore, a probable cause of some of these localized ELF nighttime field-strength variations (which are certainly not restricted to measurement locations in the northeastern United States) are changes in reflection height along the propagation path (which can lead to standing-wave effects) because of particle bombardment.

Another possible explanation for these anomalous nighttime results is that the receivers are on great-circle paths that are nearly tangential to the disturbed polar cap, in which shadow zones and interference patterns could occur.

A comparison of ELF signal-strength, atmospheric-noise, and SNR behavior during 67 low-amplitude field-strength nights has shown that large decreases in signal strength are not accompanied by large decreases in atmospheric-noise levels. The probable reason is that the signal path is a point-to-point path, while the atmospheric-noise path is essentially a nondirectional path.

Simultaneous measurements taken in Connecticut and the North-Atlantic area during the magnetically quiet period of early March 1977 (where nighttime propagation anomalies occurred 2 to 4 hr apart) have indicated that another cause for some of these anomalies is a moving nocturnal sporadic E-layer.

It now appears that theory has advanced to the point where substantial benefit would result from a concurrent-measurement program simultaneously involving nocturnal-ELF propagation and sporadic-E soundings over and about the propagation path. ELF measurements provide the only means yet of remotely monitoring ionization phenomena in an altitude range not accessible to other techniques and may be extremely useful in untangling the mysteries of this region.

Table 1. March 1977 North-Atlantic-Area Submarine Daily Field-Strength Averages

Date	WTF Phasing (deg)	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	SSTP H_ϕ (dBA/m)	$\Delta\phi$ (Night-Day) (deg)
3/1*	200	-154.4	-150.7	-152.4	-153.2	57
3/2*	200	-155.4	-150.9	-151.0	-155.0	72
3/3*	200	-151.3	-150.9	-151.5	-150.7	54
3/4*	200	-150.8	-151.0	--	-150.0	68
3/5*	200	-151.1	-149.8	-149.9	-150.6	29
3/6	110	-152.5	-150.9	-151.9	--	51
3/7	110	-151.0	-150.6	-150.3	-149.6	72
3/8	290	-153.6	-152.9	-150.8	-150.6	64
3/9	290	-151.7	-151.2	-150.2	-148.0	46
3/10	290	-150.7	-151.3	-150.0	-149.9	38
3/11	290	-152.5	--	--	--	38
3/14	290	--	-151.7	-152.0	-149.6	87
3/15	290	-150.1	--	--	--	--
3/16	290	-150.9	-151.3	-151.4	-152.9	73
3/17	290	-153.7	-155.6	-150.7	-150.8	58
3/26	290	--	-152.7	-152.4	--	80
3/27	290	-152.0	-153.0	--	--	87
Monthly Average*	-	-152.1	-151.7	-151.0	-150.9	60

*Normalized to ψ = 290 deg.

Table 2. Comparison of Connecticut Nighttime Field-Strength, Atmospheric-Noise, and SNR Behavior (1973 to 1975)

Date	Frequency (Hz)	GMT Local Time	Signal Behavior (dB)	Noise Behavior (dB)	SNR Behavior (dB)
4/19/73	76	1800-2400	Decreased $\sim$ 7	Decreased $\sim$ 4	Decreased $\sim$ 3
5/14/73	76	2000-2300	Decreased $\sim$ 6	Decreased $\sim$ 2	Decreased $\sim$ 4
5/17-5/18/73	76	2200-0100	Decreased $\sim$ 4	Increased $\sim$ 1	Decreased $\sim$ 5
9/27/73	76	1900-2130	Decreased $\sim$ 4	Decreased $\sim$ 1	Decreased $\sim$ 3
10/30-10/31/73	76	1900-0300	Level $\sim$ 3 below monthly mean	Level $\sim$ equal to monthly mean	Level $\sim$ 3 below monthly mean
11/21-11/22/73	76	2200-0100	Decreased $\sim$ 4	Decreased $\sim$ 1	Decreased $\sim$ 3
11/24-11/25/73	76	2000-0300	Level $\sim$ 3 below monthly mean	Level $\sim$ 1 above monthly mean	Level $\sim$ 4 below monthly mean
1/25-1/26/74	42	1800-0200	Decreased $\sim$ 8	$\sim$ Constant	Decreased $\sim$ 8
3/19-3/20/74	42	1800-0100	Decreased $\sim$ 6	$\sim$ Constant	Decreased $\sim$ 6
9/11-9/12/74	76	2200-0200	Decreased $\sim$ 4	Decreased $\sim$ 1	Decreased $\sim$ 3
9/19-9/20/74	42	2100-0400	Decreased $\sim$ 5	$\sim$ Constant	Decreased $\sim$ 5
9/21-9/22/74	42	2100-0400	Level $\sim$ 2.5 below monthly mean	Level $\sim$ equal to monthly mean	Level $\sim$ 2.5 below monthly mean
9/26-9/27/74	42	2000-0100	Decreased $\sim$ 5	$\sim$ Constant	Decreased $\sim$ 5
9/28-9/29/74	42	2100-0400	Level $\sim$ 2 below monthly mean	Level $\sim$ 2 above monthly mean	Level $\sim$ 4 below monthly mean
10/30/74	76	2100-2300	Decreased $\sim$ 4	$\sim$ Constant	Decreased $\sim$ 4
3/14-3/15/75	42	2100-0300	Decreased $\sim$ 9	$\sim$ Constant	Decreased $\sim$ 9
3/15-3/16/75	42	2100-0300	Decreased $\sim$ 3	Increased $\sim$ 1	Decreased $\sim$ 4
3/17-3/18/75	42	2200-0200	Decreased $\sim$ 4	$\sim$ Constant	Decreased $\sim$ 4
3/18-3/19/75	42	2100-0100	Decreased $\sim$ 4	$\sim$ Constant	Decreased $\sim$ 4
3/20-3/21/75	42	2200-0400	Decreased $\sim$ 3	Decreased $\sim$ 1	Decreased $\sim$ 2
3/27-3/28/75	42	2100-0400	Decreased $\sim$ 6	Decreased $\sim$ 3	Decreased $\sim$ 3
3/30-3/31/75	42	2200-0400	Decreased $\sim$ 4	$\sim$ Constant	Decreased $\sim$ 4
3/31-4/1/75	42	2000-0000	Decreased $\sim$ 3.5	Decreased $\sim$ 1	Decreased $\sim$ 2.5
4/3-4/4/75	42	2200-0100	Decreased $\sim$ 4	Increased $\sim$ 2	Decreased $\sim$ 6
9/21-9/22/75	76	2100-0100	Decreased $\sim$ 3	Increased $\sim$ 1	Decreased $\sim$ 4
9/22-9/23/75	76	2100-0100	Decreased $\sim$ 3	$\sim$ Constant	Decreased $\sim$ 3
9/23-9/24/75	76	2100-0100	Decreased $\sim$ 3	$\sim$ Constant	Decreased $\sim$ 3
9/24-9/25/75	76	2100-0100	Decreased $\sim$ 4	Increased $\sim$ 1	Decreased $\sim$ 5
9/25-9/26/75	76	2100-0100	Decreased $\sim$ 3	$\sim$ Constant	Decreased $\sim$ 3
9/26-9/27/75	76	2100-0100	Decreased $\sim$ 6	Increased $\sim$ 2	Decreased $\sim$ 8
10/27-10/28/75	76	1900-0230	Level $\sim$ 4.5 below monthly mean	Level $\sim$ 3 above monthly mean	Level $\sim$ 7.5 below monthly mean
10/28-10/28/75	76	2000-0230	Decreased $\sim$ 5	$\sim$ Constant	Decreased $\sim$ 5
10/29-10/30/75	76	1900-0230	Level $\sim$ 2.5 above monthly mean	Level $\sim$ equal to monthly mean	Level $\sim$ 2.5 above monthly mean
11/19-11/20/75	76	1700-0400	Level $\sim$ 2.5 above monthly mean	Level $\sim$ equal to monthly mean	Level $\sim$ 2.5 above monthly mean
			Average Decrease $\sim$ 4.5	Average Decrease $\sim$ 0	Average Decrease $\sim$ 4.5

Table 3. Comparison of Connecticut Nighttime Field-Strength, Effective Atmospheric-Noise, and SNR Behavior (1976)

Date	Frequency (Hz)	GMT Local Time	Signal Behavior (dB)	Noise Behavior (dB)	SNR Behavior (dB)
8/3	76	0400-0800	Decreased ∿ 3	∿ Constant	Decreased ∿ 3
8/25	76	0100-0700	Decreased ∿ 4.5	Decreased ∿ 3	Decreased ∿ 1.5
9/12	76	0400-0600	Decreased ∿ 2.5	∿ Constant	Decreased ∿ 2.5
9/21	76	0600-0900	Decreased ∿ 5	Decreased ∿ 1	Decreased ∿ 4
9/23	76	0500-0800	Decreased ∿ 4	Decreased ∿ 0.5	Decreased ∿ 3.5
9/26	76	0400-0700	Decreased ∿ 4	∿ Constant	Decreased ∿ 4
9/28	76	0400-0700	Decreased ∿ 3	Decreased ∿ 1	Decreased ∿ 2
9/29	76	0400-0700	Decreased ∿ 4	Decreased ∿ 1	Decreased ∿ 3
9/30	76	0400-0600	Decreased ∿ 4	∿ Constant	Decreased ∿ 4
10/1	76	0300-0500	Decreased ∿ 4	Decreased ∿ 1	Decreased ∿ 3
10/3	76	0400-0600	Decreased ∿ 4	∿ Constant	Decreased ∿ 4
10/20	76	0430-0830	Decreased ∿ 3	Decreased ∿ 1	Decreased ∿ 2
10/30	76	0500-0730	Decreased ∿ 2.5	∿ Constant	Decreased ∿ 2.5
11/12	76	0600-0900	Decreased ∿ 4	∿ Constant	Decreased ∿ 4
11/22	76	0230-0800	Decreased ∿ 3.5	Decreased ∿ 1	Decreased ∿ 2.5
12/8	76	0400-0700	Decreased ∿ 3.5	Decreased ∿ 0.5	Decreased ∿ 3
12/18	76	0200-0330	Decreased ∿ 5	Decreased ∿ 1	Decreased ∿ 4
			Average Decrease 3.7	Average Decrease 0.6	Average Decrease 3.1

Table 4. Comparison of Connecticut Nighttime Field-Strength, Atmospheric-Noise, and SNR Behavior (March 1977)

Date	Frequency (Hz)	GMT Local Time	Signal Behavior (dB)	Noise Behavior (dB)	SNR Behavior (dB)
3/1	76	0200-0900	Decreased ∿ 6	Decreased ∿ 1	Decreased ∿ 5
3/2	76	2200-0830	Decreased ∿ 7	Decreased ∿ 2	Decreased ∿ 5
3/3	76	0200-0800	Decreased ∿ 6	Decreased ∿ 3	Decreased ∿ 3
3/4	76	0200-0700	Decreased ∿ 7	Decreased ∿ 1	Decreased ∿ 6
3/5	76	0230-0730	Decreased ∿ 5.5	Increased ∿ 4	Decreased ∿ 9.5
3/10	76	0400-0800	Decreased ∿ 5	∿ Constant	Decreased ∿ 5
3/16	76	0400-0930	Decreased ∿ 5	Decreased ∿ 3	Decreased ∿ 2
3/17	76	0000-0600	∿ 3 below 3/16 avg.	∿ Same as 3/16	Decreased ∿ 3
3/18	76	2200-0630	Decreased ∿ 6	Decreased ∿ 4	Decreased ∿ 2
3/27	76	0200-0800	Decreased ∿ 4	∿ Constant	Decreased ∿ 4
3/28	76	2300-0630	Decreased ∿ 5	Decreased ∿ 3	Decreased ∿ 2
3/30	76	2300-0830	Decreased ∿ 5	Decreased ∿ 2	Decreased ∿ 3
			Average Decrease ∿ 5.3	Average Decrease ∿ 1.3	Average Decrease ∿ 4.0

Table 5. March 1977 Submarine Data, Comparison of Nighttime Minimum Field-Strength SNR's With Nighttime Maximum Field-Strength SNR's

Date	Time of Minimum Nighttime Field Strength (GMT)	Time of Maximum Nighttime Field Strength (GMT)	Approximate Signal Strength Difference (dB)	Effective Noise Difference (dB)	Approximate SNR Difference (dB)
3/1	0400	0700	10	0	10
3/2	0530	0730	11	0	11
3/3	0430	0800	6	-1	7
3/4	0400	0730	5.5	0	5.5
3/7	0230	0730	5	-2	7
3/8	0700	0100	6	1	5
3/10	0530	0130	7.5	1	6.5
3/11	0600	0100	6	1	5
3/15	0600	0400	6.5	0	6.5
3/17	0800	0630	6.5	1.5	5
3/27	0530	0130	7	0	7
			Average Difference 6.8	Average Difference 0.0	Average Difference 6.8

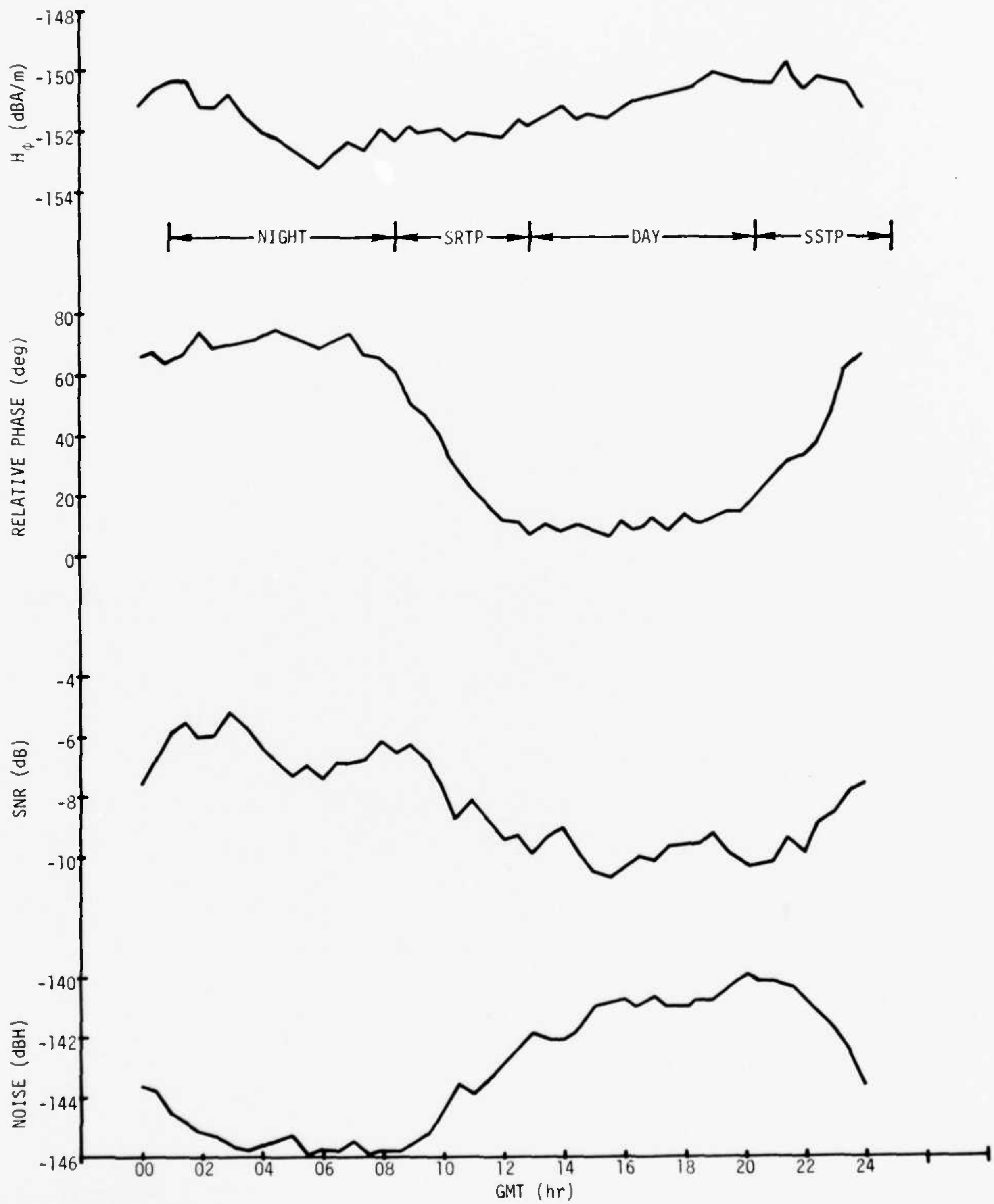

Figure 1. North-Atlantic Area, 6 to 27 March 1977, Average Data Versus GMT (ψ = 291 deg)

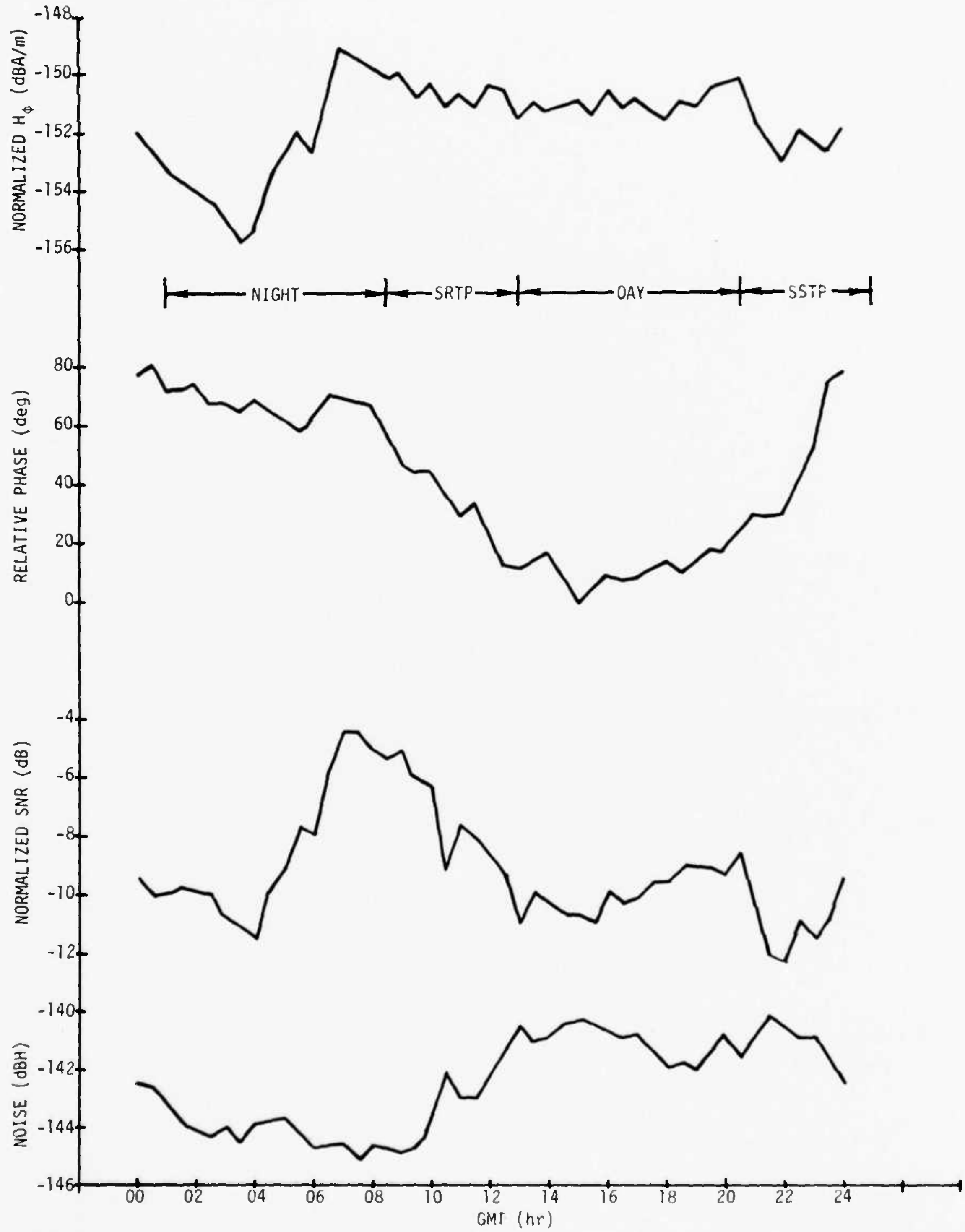

Figure 2. North-Atlantic Area, 1 to 5 March 1977, Average Data Versus GMT (ψ = 201 deg)

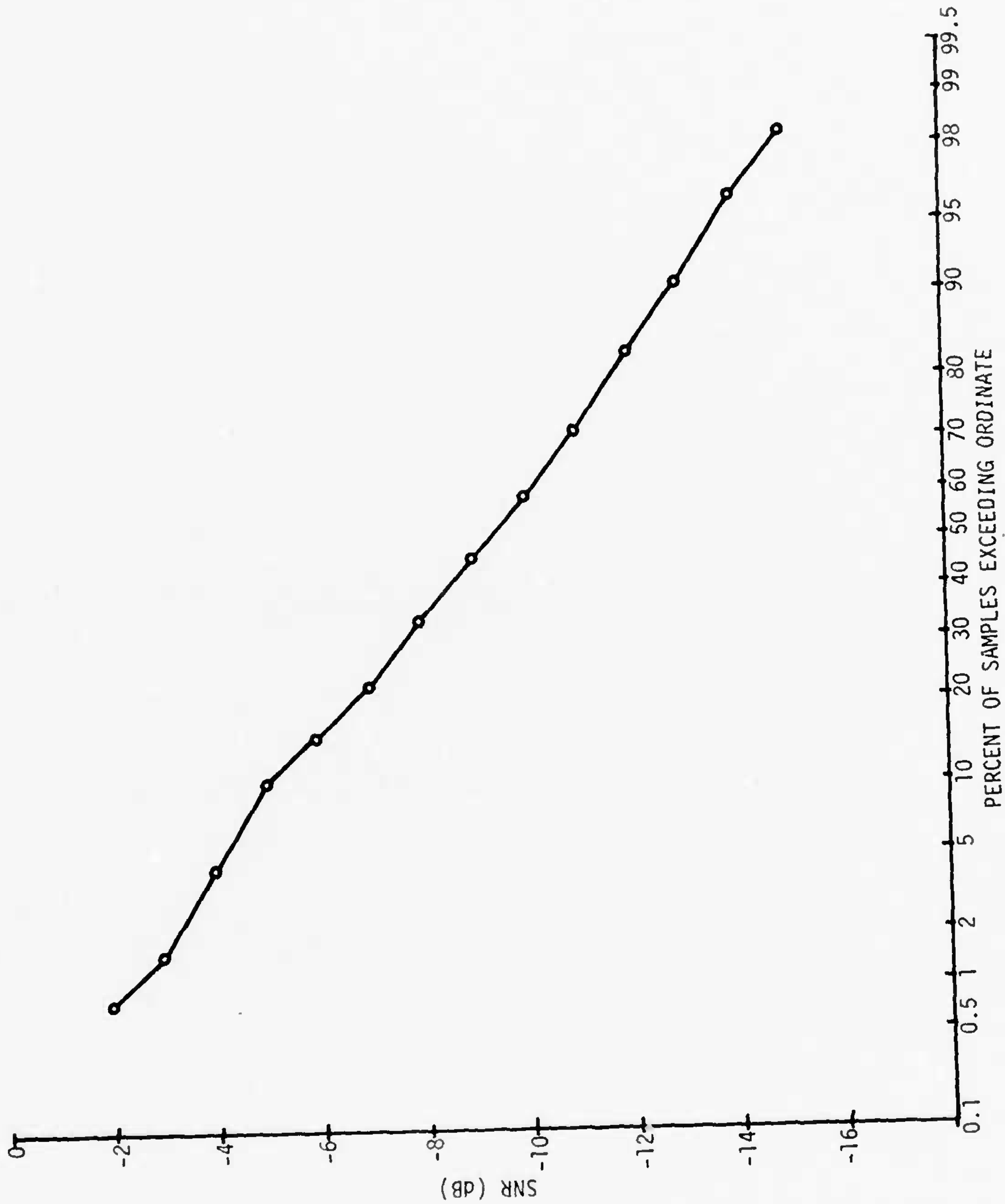

Figure 3. March 1977 North-Atlantic-Area SNR Distribution (N = 507, ψ = 291 deg)

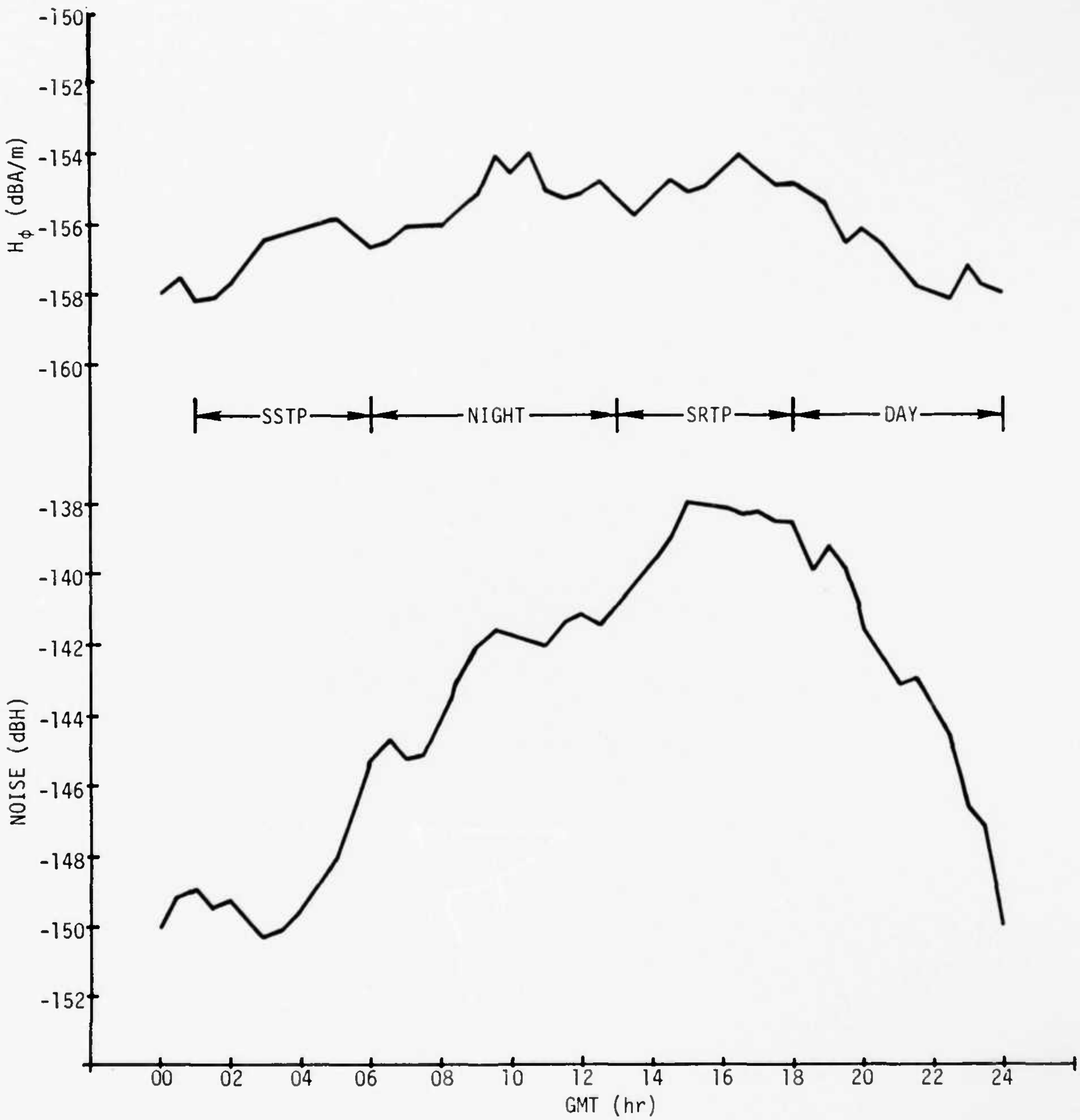

Figure 4. March 1977 Hawaii-Area Data Versus GMT (ψ = 291 deg, ρ ~ 7 Mm)

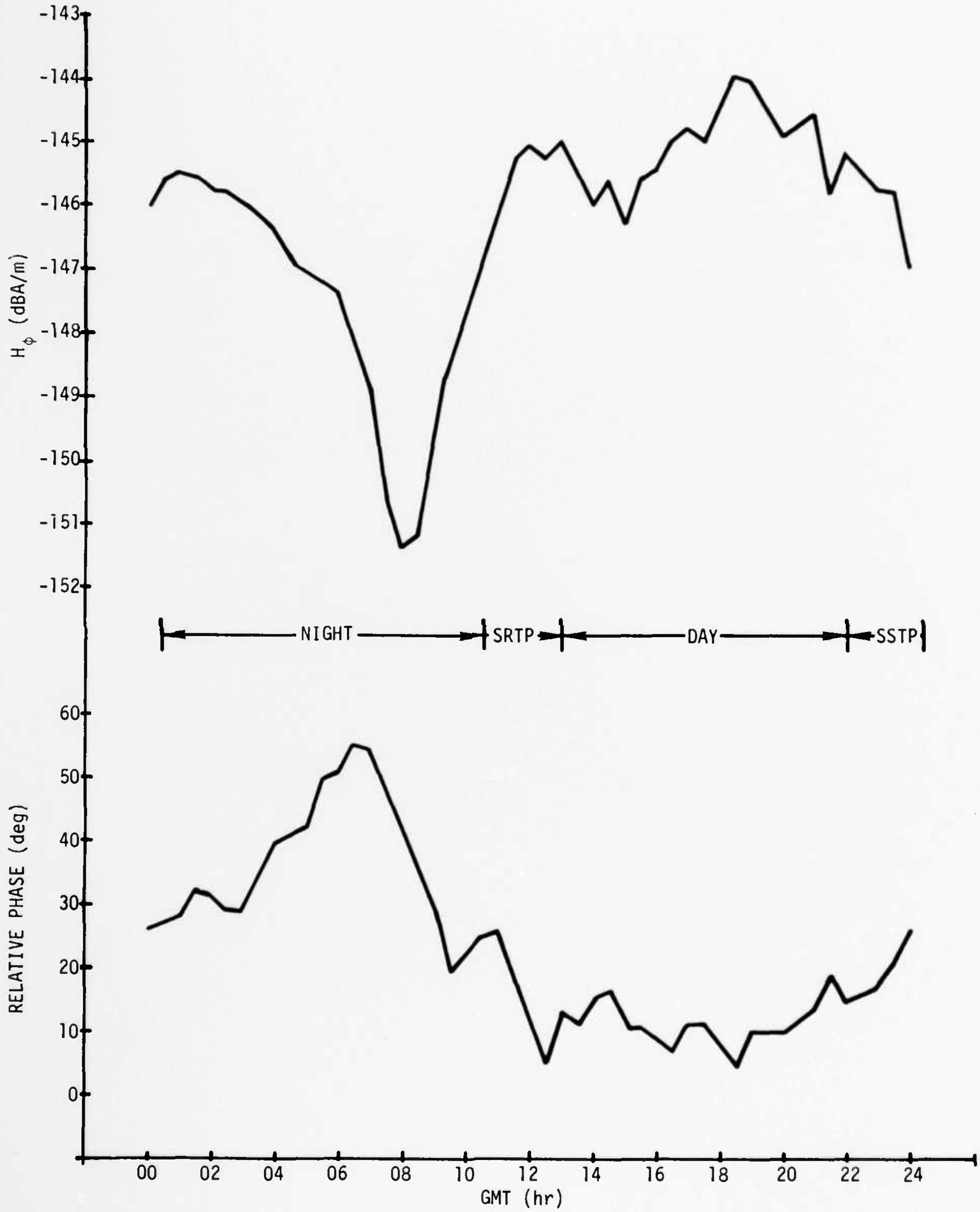

Figure 5. Connecticut Field Strength Versus GMT (ψ = 204 deg), 22 February 1977

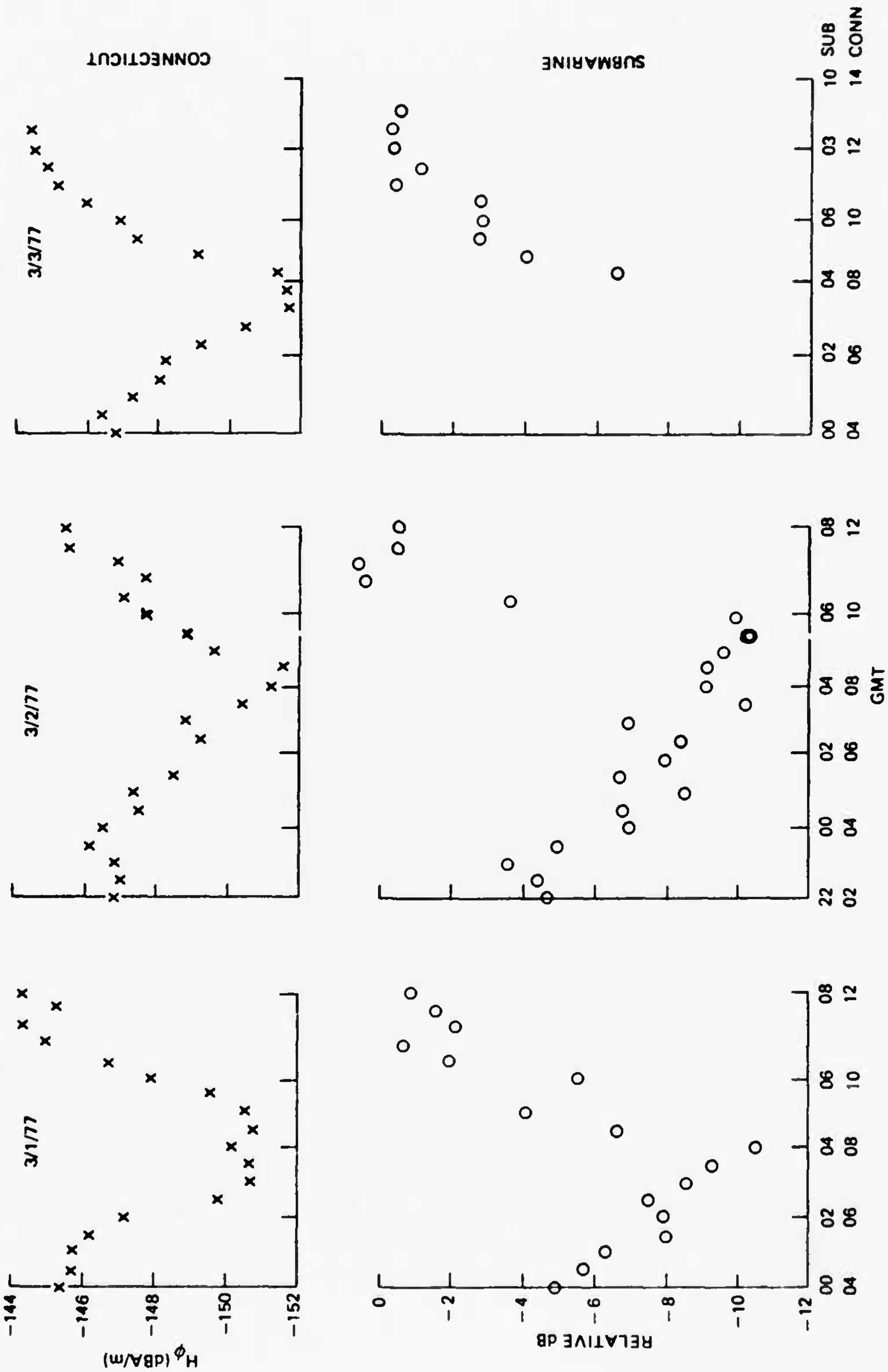

Figure 6. Comparison of Connecticut and Submarine Data, 1 to 3 March 1977

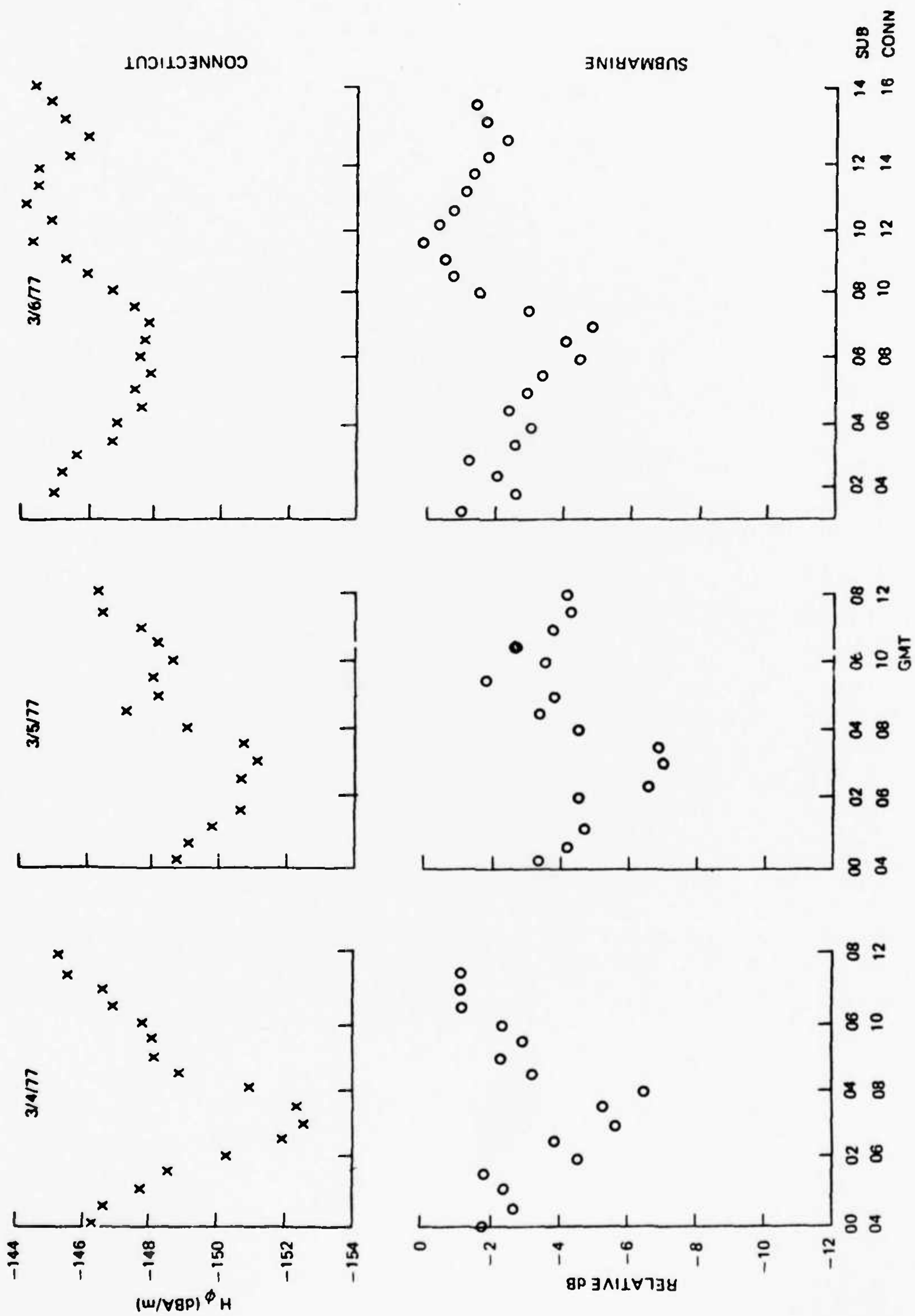

Figure 7. Comparison of Connecticut and Submarine Data, 4 to 6 March 1977

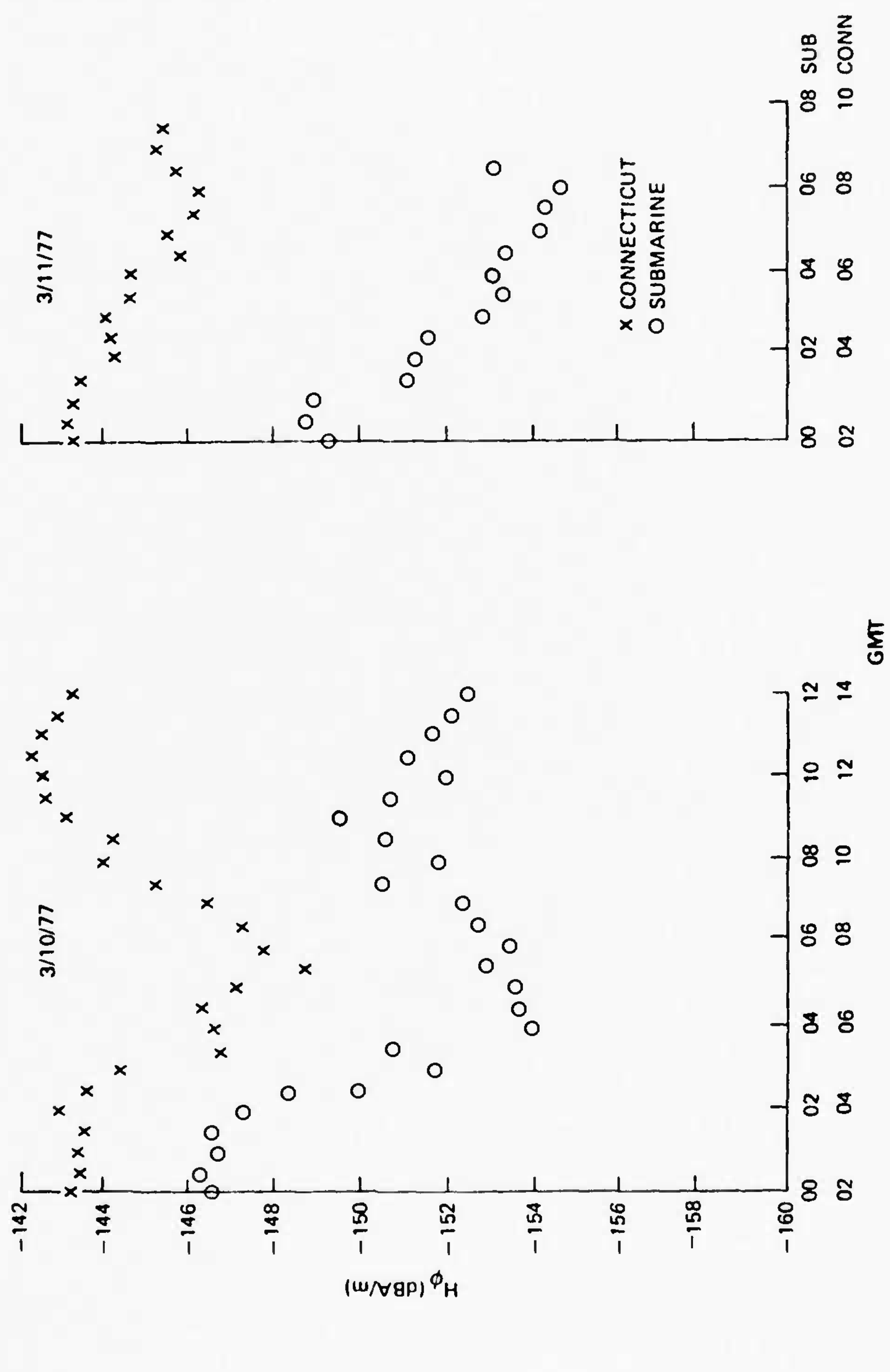

Figure 8. Comparison of Connecticut and Submarine Data, 10 and 11 March 1977

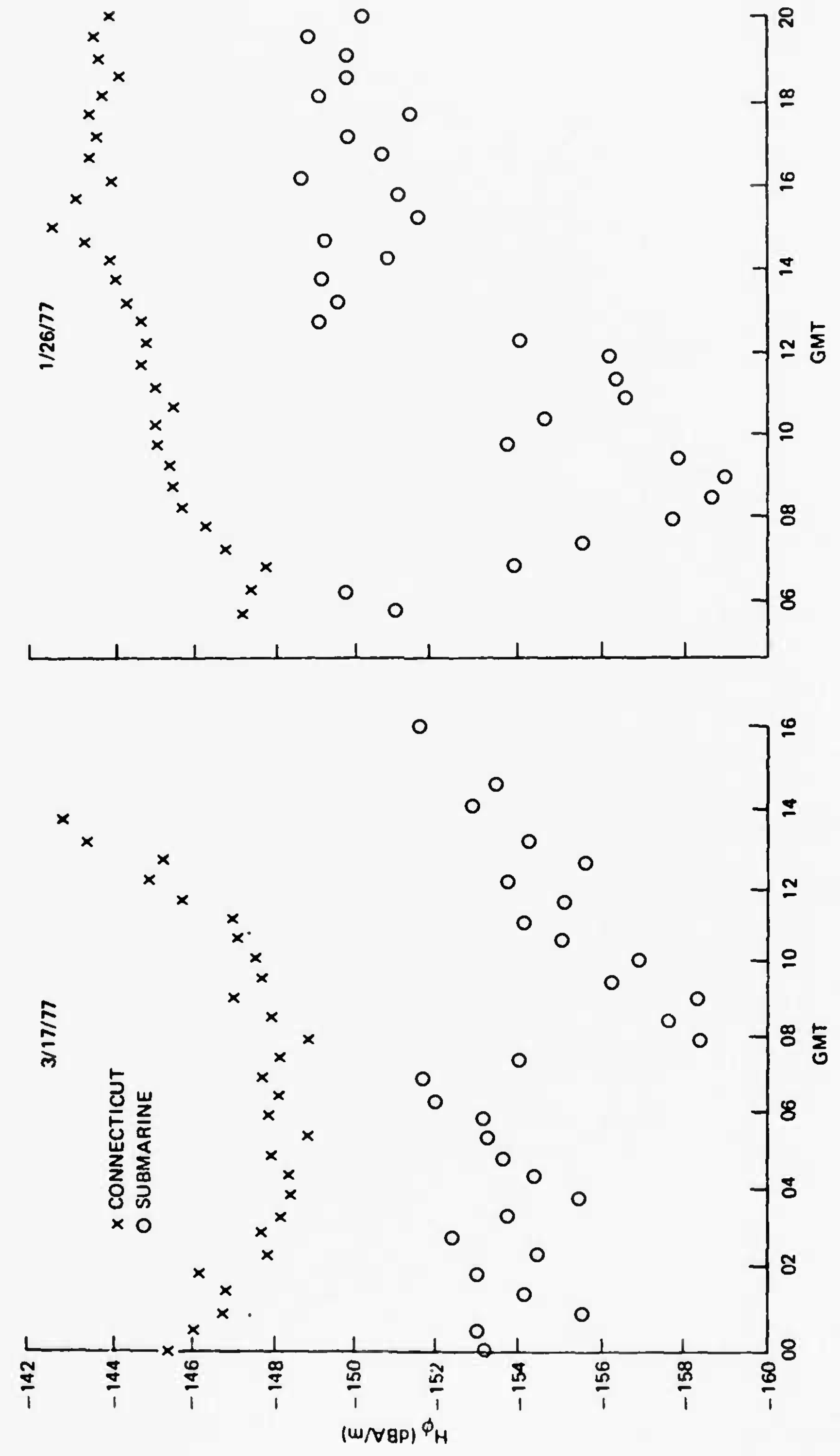

Figure 9. Comparison of Connecticut and Submarine Data, 26 January and 17 March 1977

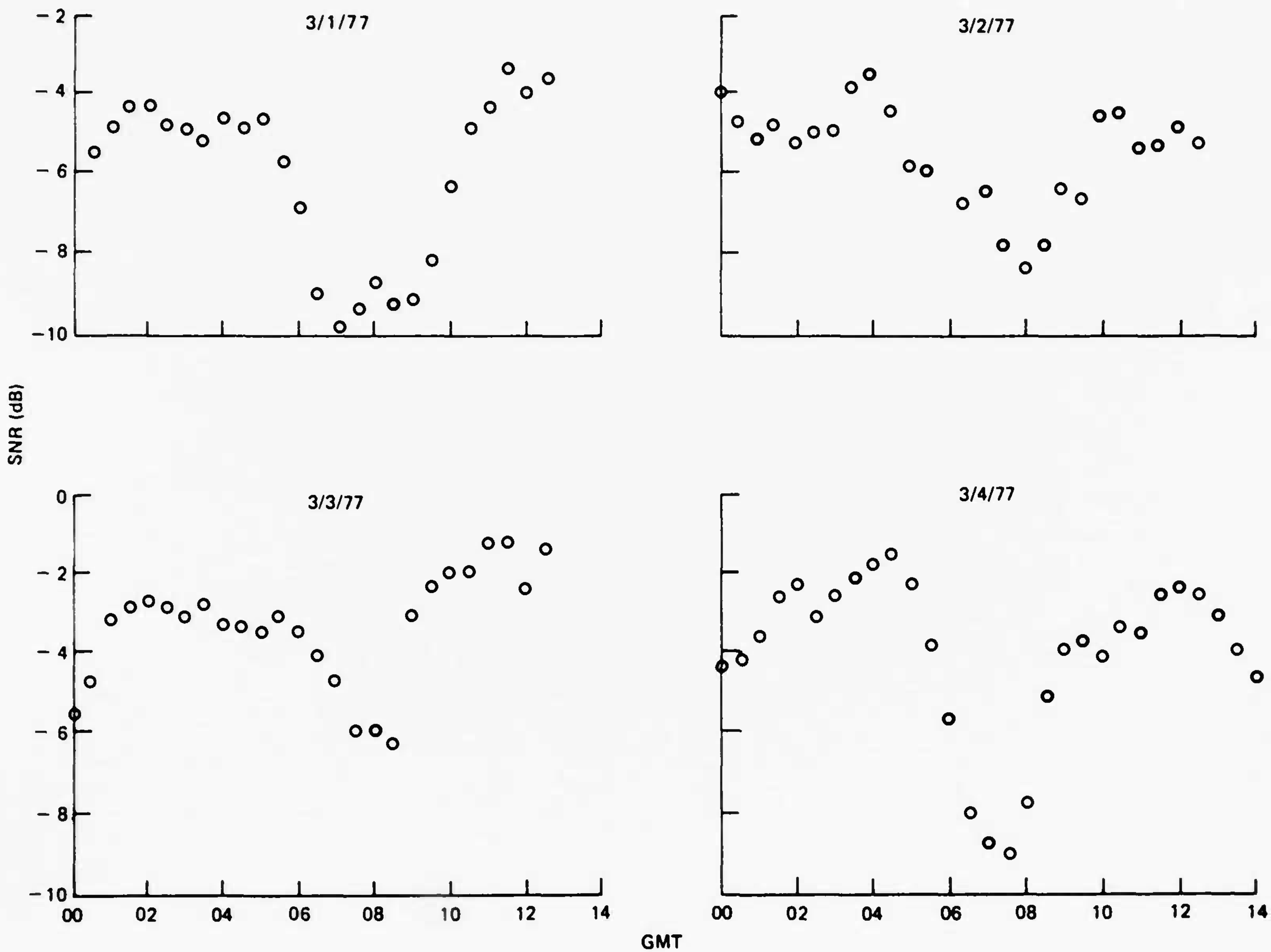

Figure 10. SNR Versus GMT for 1 to 4 March 1977 Connecticut Data

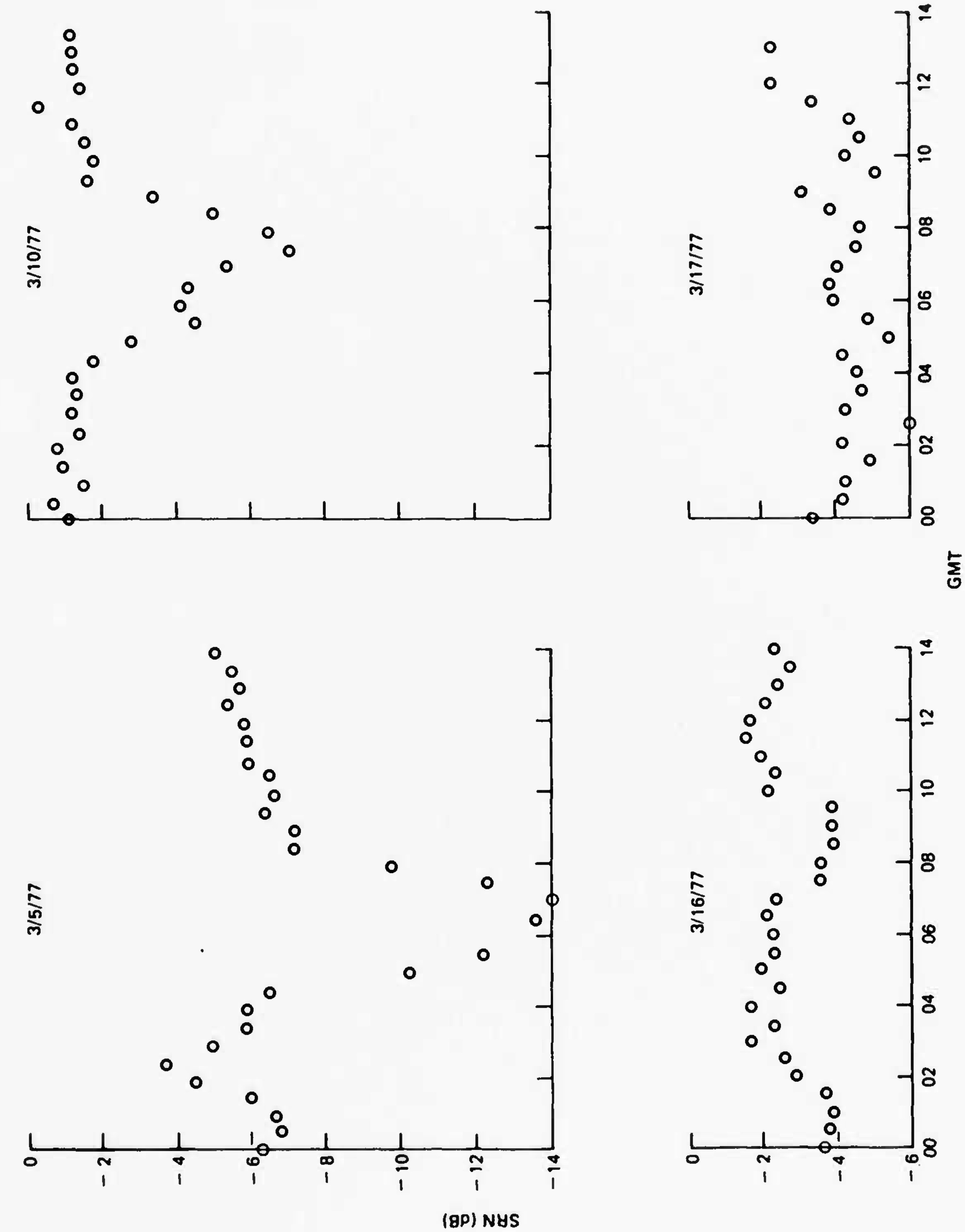

Figure 11. SNR Versus GMT for 5, 10, 16, and 17 March 1977 Connecticut Data

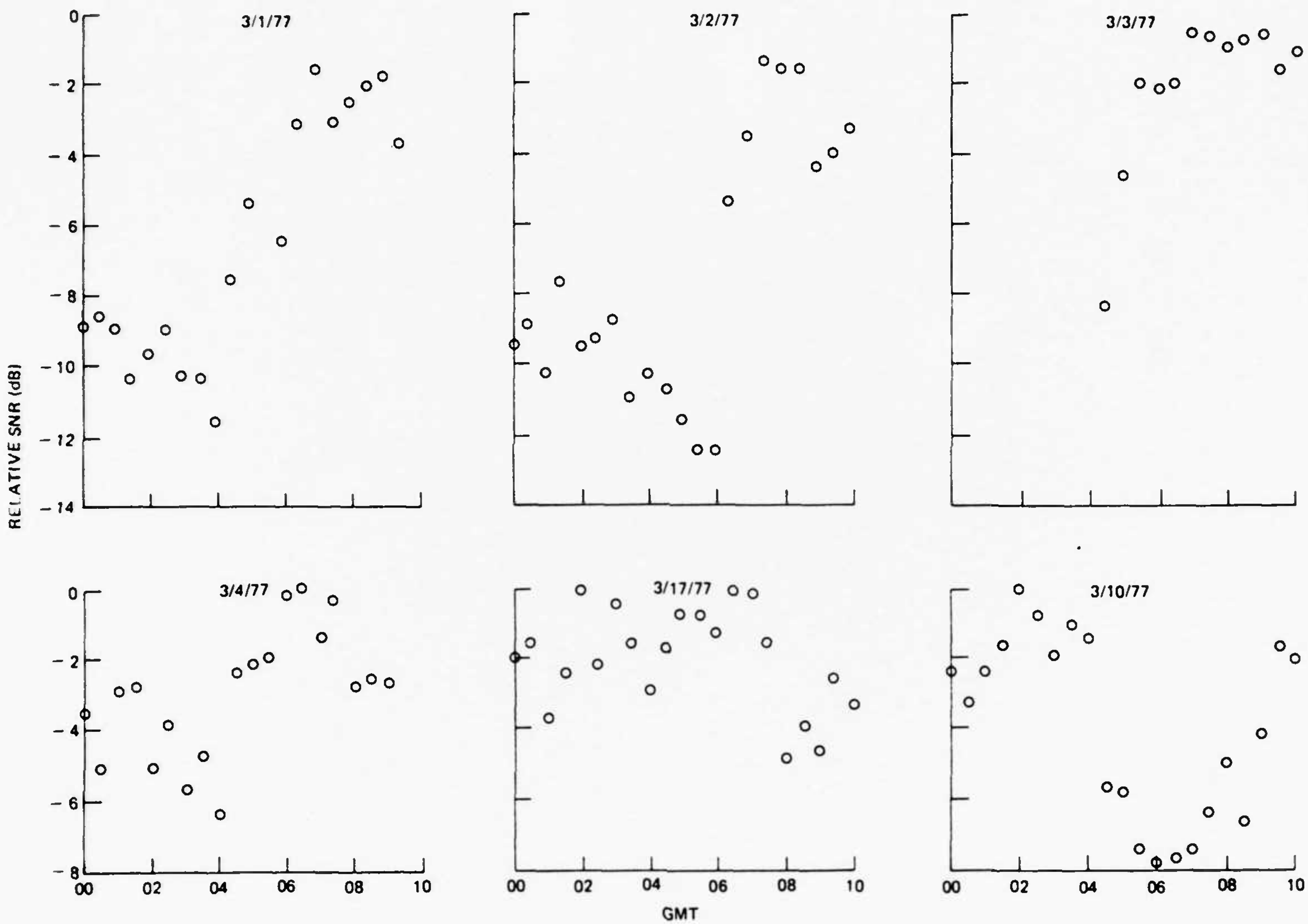

Figure 12. Relative SNR Versus GMT for 1 to 4, 10, and 17 March 1977 Submarine Data

REFERENCES

1. P. R. Bannister, F. J. Williams, A. L. Dahlvig, and W. A. Kraimer, "Wisconsin Test Facility Transmitting Antenna Pattern and Steering Measurements," IEEE Transactions on Communications, vol. COM-22, no. 4, 1974, pp. 412-418.

2. D. P. White, ELF Propagation Measurements (Phase III - Fall 1971), Technical Note 1972-21, MIT Lincoln Laboratory, Lexington, MA, 31 July 1972.

3. J. R. Davis and W. D. Meyers, Observations of ELF Signal and Noise Variability on Northern Latitude Paths, NRL Report 7923, Naval Research Laboratory, Washington, DC, 11 November 1975.

4. J. E. Evans and A. S. Griffiths, "Design of a Sanguine Noise Processor Based Upon World-wide Extremely Low Frequency (ELF) Recordings," IEEE Transactions on Communications, vol. COM-22, no. 4, 1974, pp. 528-539.

5. P. R. Bannister, ELF PVS Field Strength Measurements, January 1977, NUSC Technical Report 6879, Naval Underwater Systems Center, New London, CT (to be published).

6. P. R. Bannister, "Farfield Extremely Low Frequency (ELF) Propagation Measurements, 1970-72," IEEE Transactions on Communications, vol. COM-22, no. 4, 1974, pp. 468-474.

7. P. R. Bannister, "Variations in Extremely Low Frequency Propagation Parameters," Journal of Atmospheric and Terrestrial Physics, vol. 37, no. 9, 1975, pp. 1203-1210.

8. A. S. Griffiths, Measurements of ELF Noise Processing, Technical Note 1975-33, MIT Lincoln Laboratory, Lexington, MA, 2 September 1975.

9. J. Galejs, Terrestrial Propagation of Long Electromagnetic Waves, Pergamon Press, NY, 1972, ch. 7.

10. D. P. White and D. K. Willim, "Propagation Measurements in the Extremely Low Frequency (ELF) Band," IEEE Transactions on Communications, vol. COM-22, no. 4, 1974, pp. 457-467.

11. P. R. Bannister, "Some Notes on ELF Earth-Ionosphere Waveguide Daytime Propagation Parameters," IEEE Transactions on Antennas and Propagation, vol. AP-27, no. 5, 1979, pp. 696-698.

12. P. R. Bannister, "Summary of Extremely Low Frequency (ELF) Field Strength Measurements Made in Connecticut During 1975," Radio Science, vol. 14, no. 1, 1979, pp. 103-108.

13. P. R. Bannister, ELF Field Strength Measurements Made in Connecticut During 1976, NUSC Technical Report 5853, Naval Underwater Systems Center, New London, CT, 11 September 1978.

14. P. R. Bannister, "Overview of ELF Propagation," NATO/AGARD CPP No. 305, Medium, Long, and Very Long Wave Propagation (at frequencies less than 300 kHz), Brussels, Belgium, 21-25 September 1981.

15. P. R. Bannister, "Localized ELF Nocturnal Propagation Anomalies," Radio Science, vol. 17, no. 3, 1982, pp. 627-634.

16. P. R. Bannister et al., Extremely Low Frequency (ELF) Propagation, NUSC Scientific and Engineering Studies, Naval Underwater Systems Center, New London, CT, February 1980, 550 pages.

17. P. R. Bannister and F. J. Williams, "Further Examples of the Nighttime Variations of ELF Signal Strengths in Connecticut," Journal of Atmospheric and Terrestrial Physics, vol. 38, no. 3, 1976, pp. 313-317.

18. P. R. Bannister, F. J. Williams, J. R. Katan, and R. F. Ingram, "Nighttime Variations of Extremely Low Frequency (ELF) Signal Strengths in Connecticut," IEEE Transactions on Communications, vol. COM-22, no. 4, 1974, pp. 474-476.

19. J. R. Davis, "Localized Nighttime D-Region Disturbances and ELF Propagation," Journal of Atmospheric and Terrestrial Physics, vol. 38, no. 12, 1976, pp. 1309-1317.

20. J. R. Davis, "ELF Propagation Irregularities on Northern and Midlatitude Paths," in ELF-VLF Radio Wave Propagation, edited by J. Holtet, 1974, pp. 263-277, D. Reidel, Dordrecht, Netherlands.

21. C. J. Sechrist, Jr., Thermospheric Circulation, edited by W. L. Webb, 1972, p. 261, MIT Press, Cambridge, MA.

22. W. N. Spjeldvik and R. M. Thorne, "The Cause of Storm After-Effects in the Middle Latitude D-region," Journal of Atmospheric and Terrestrial Physics, vol. 37, no. 5, 1975, pp. 777-795.

23. W. N. Spjeldvik and R. M. Thorne, "A Simplified D-region Model and its Application to Magnetic Storm After-Effects," Journal of Atmospheric and Terrestrial Physics, vol. 37, no. 10, 1975, pp. 1313-1325.

24. D. S. Wratt, "Variations in Electron Density in the Middle Latitude D-region Above Urbana, Illinois," Journal of Atmospheric and Terrestrial Physics, vol. 39, no. 5, 1977, pp. 607-617.

25. P. H. G. Dickinson and F. D. G. Bennett, "Diurnal Variations in the D-region During a Storm After-Effects," Journal of Atmospheric and Terrestrial Physics, vol. 40, no. 5, 1978, pp. 549-558.

26. W. L. Imhof, J. B. Reagan, E. E. Gaines, T. R. Larsen, J. R. Davis, and W. Moler, "Coordinated Measurements of ELF Transmission and the Precipitation of Energetic Particles into the Ionosphere," Radio Science, vol. 13, no. 4, 1978, pp. 712-727.

27. R. Barr, "The Effect of Sporadic E on the Nocturnal Propagation of ELF Radio Waves," Journal of Atmospheric and Terrestrial Physics, vol. 39, no. 11/12, 1977, pp. 1379-1387.

28. R. A. Pappert and W. F. Moler, "A Theoretical Study of ELF Normal Mode Reflection and Absorption Produced by Nighttime Ionospheres," Journal of Atmospheric and Terrestrial Physics, vol. 40, no. 9, 1978, pp. 1031-1045.

29. R. A. Pappert, "Effects of a Large Patch of Sporadic E on Nighttime Propagation at Lower ELF," Journal of Atmospheric and Terrestrial Physics, vol. 42, no. 5, 1980, pp. 417-425.

30. R. A. Pappert and L. R. Shockey, Effects of Strong Local Sporadic E on ELF Propagation, NOSC TR 282, Naval Ocean Systems Center, San Diego, CA, 15 August 1978.

31. E. C. Field and R. G. Joiner, "An Integral-Equation Approach to Long-Wave Propagation in a Non-Stratified Earth-Ionosphere Waveguide," Radio Science, vol. 14, no. 6, 1979, pp. 1057-1068.

32. E. C. Field and R. G. Joiner, "Effects of Lateral Ionospheric Gradients on ELF Propagation," Radio Science, vol. 17, no. 3, 1982, pp. 693-700.

Appendix A

NORTH-ATLANTIC-AREA SUBMARINE DAILY DATA

The daily field-strength (both amplitude and relative phase), effective-noise, and SNR values are plotted versus GMT in figures A-1 to A-14 in this appendix.

The WTF antenna phasing (ψ) was 201 deg from 1 to 5 March, 111 deg on 6 and 7 March, and 291 deg during the rest of the month. The WTF transmitting frequency was 76 ±4 Hz. For comparison purposes, the 1 through 5 March data (ψ = 201 deg) are normalized to a WTF antenna phasing of 291 deg.

With the exception of the 9 and 16 March data (figures A-9 and A-12), amplitude peak-to-trough variations of 5 dB or greater can be seen to have occurred during the nighttime measurement period (0100 to 0830 GMT). The largest variations in the nighttime measured field strength (10 and 11 dB) occurred on 1 March from 0400 to 0700 GMT and on 2 March from 0600 to 0700 GMT. The average nighttime field strengths measured during these two nights were also the lowest measured during the month.

The night-to-day relative phase variation was quite variable (i.e., $\Delta\phi$ = 60 ±30 deg), with the largest variation (87 deg) occurring on 14 and 27 March (figures A-11 and A-14) and the smallest variation (29 deg) occurring on 5 March (figure A-5). The most unusual relative-phase variation also occurred on 5 March where the relative phase first decreased 50 deg and then increased 55 deg during the nighttime measurement period. Referring to figure A-5, we see that the nighttime (0100 to 0830) amplitude, relative-phase, and effective-noise plots are very similar to each other. This is also true for the 5 March Connecticut data (in appendix B).

It should be noted that all of the submarine effective-noise data presented in this report are contaminated to some degree by submarine-generated noise (external or internal to the submarine). Thus, the effective-noise values presented here are on the high side.

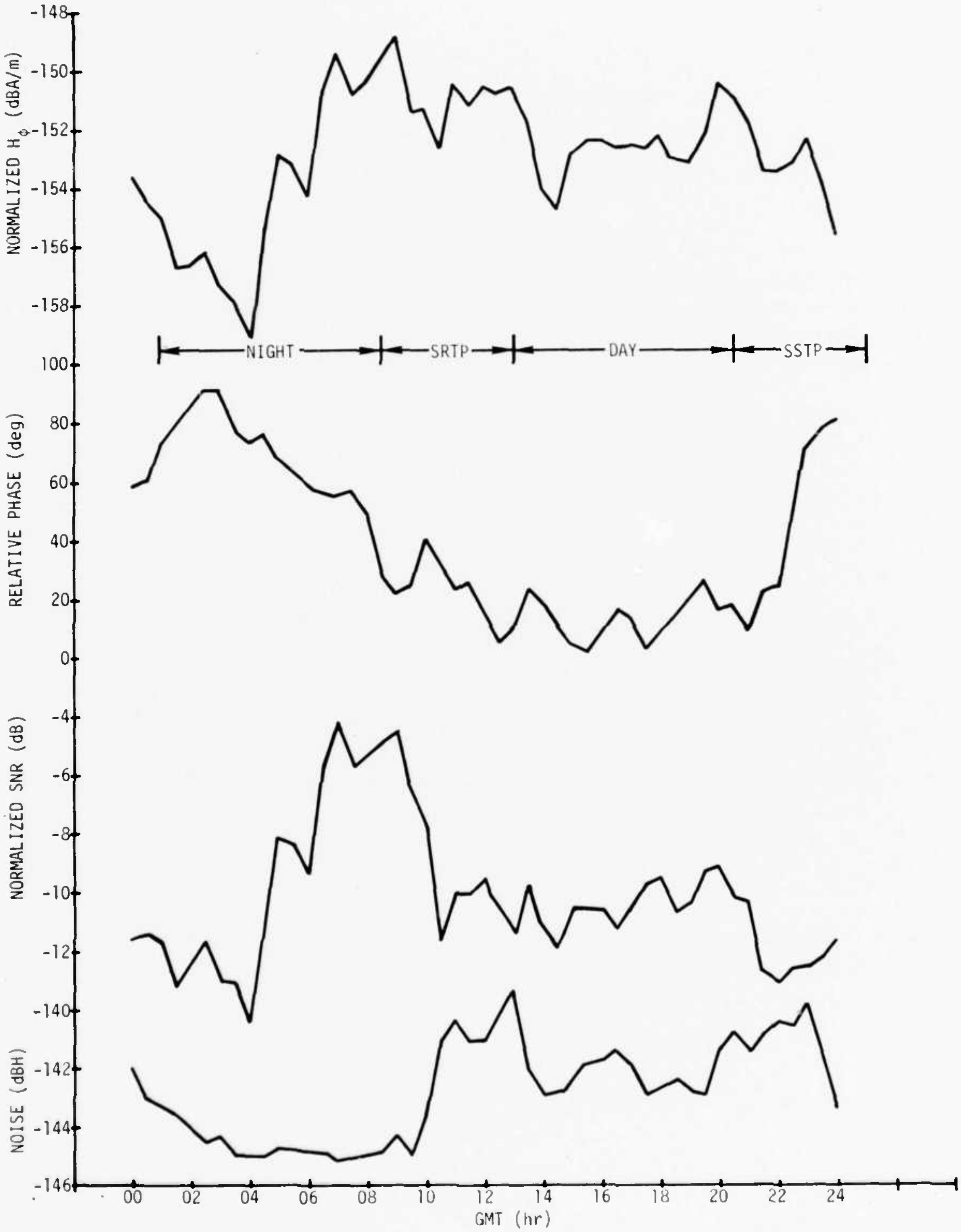

Figure A-1. Submarine Data Versus GMT
(ψ = 201 deg), 1 March 1977

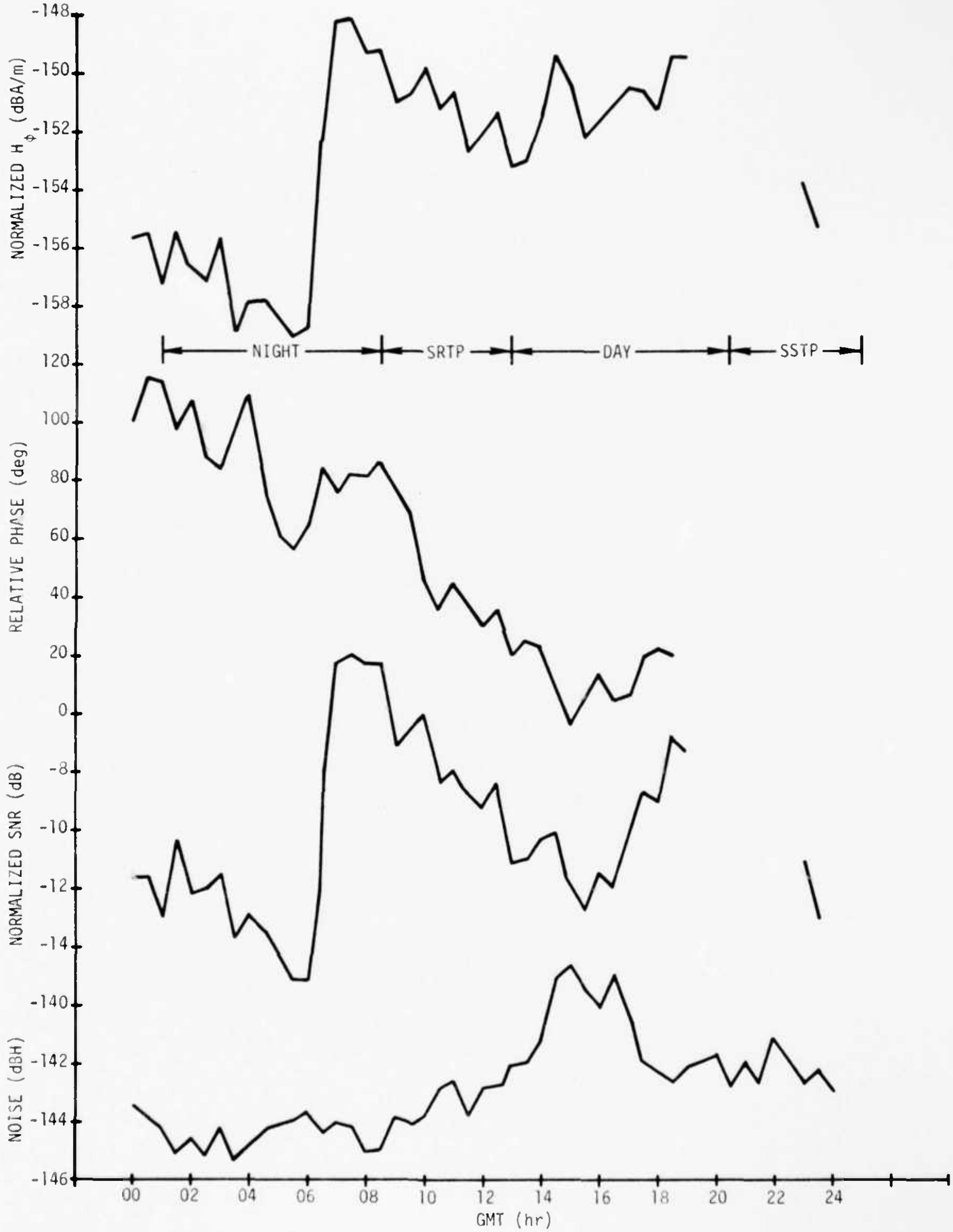

Figure A-2. Submarine Data Versus GMT
(ψ = 201 deg), 2 March 1977

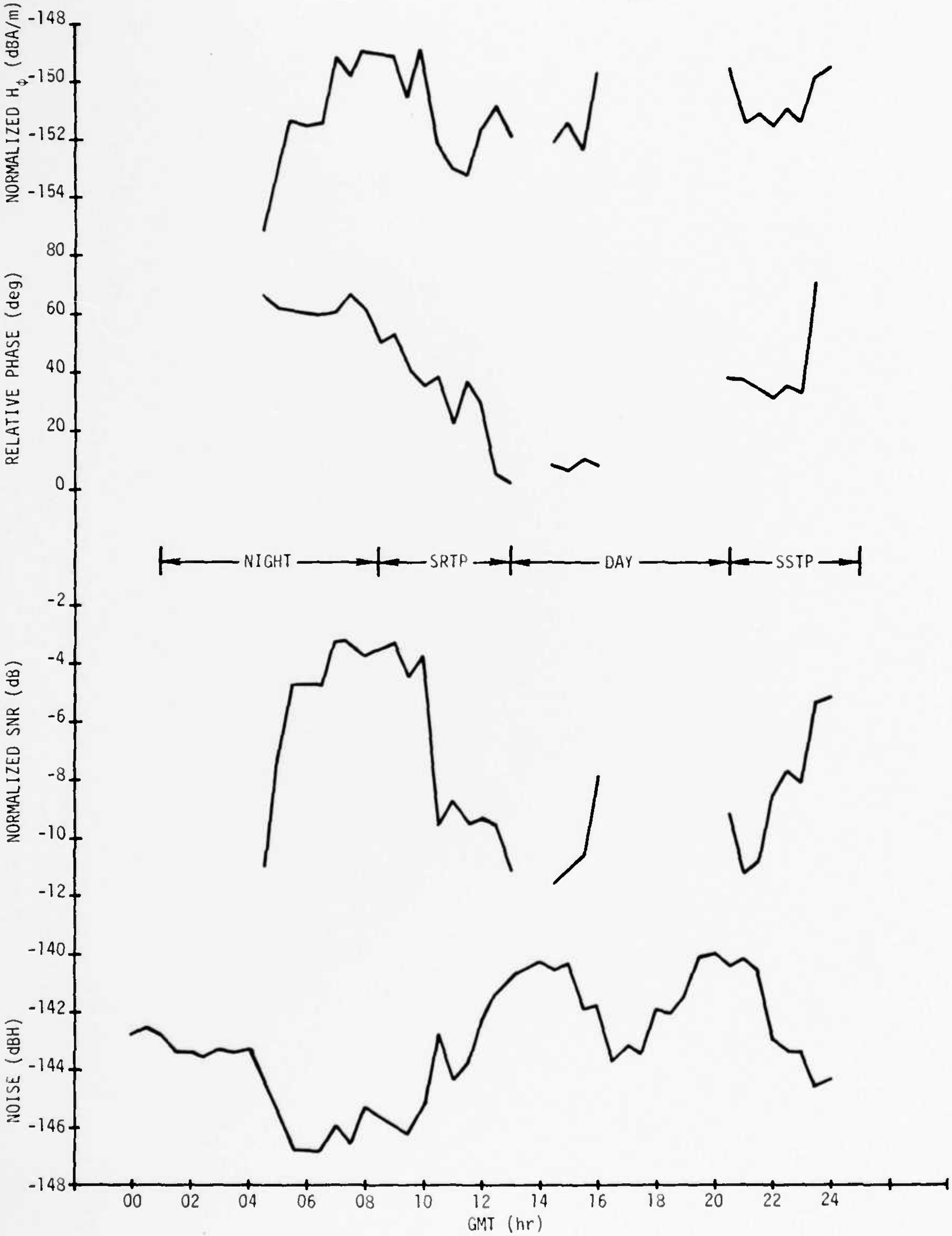

Figure A-3. Submarine Data Versus GMT
(ψ = 201 deg), 3 March 1977

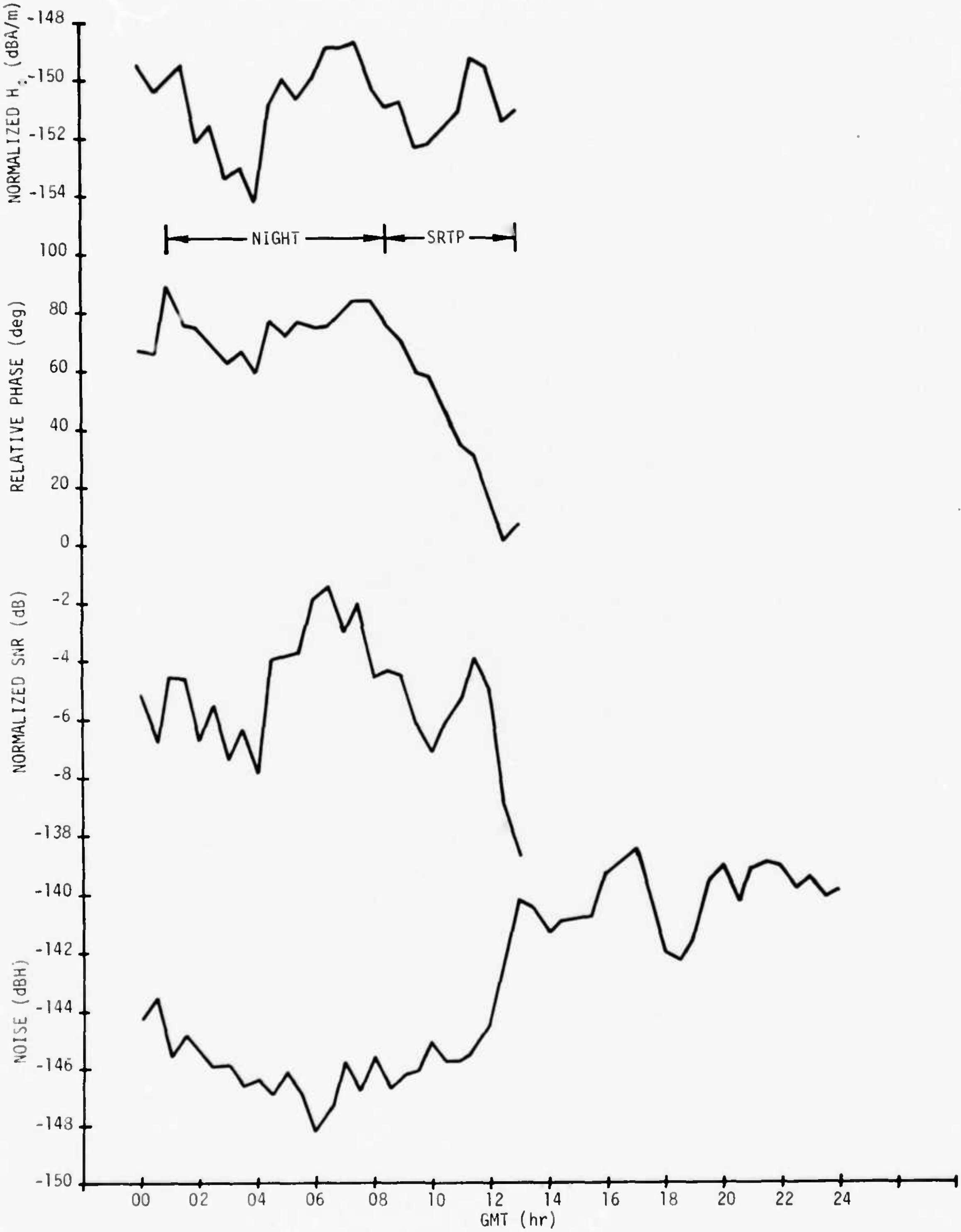

Figure A-4. Submarine Data Versus GMT
(ψ = 201 deg), 4 March 1977

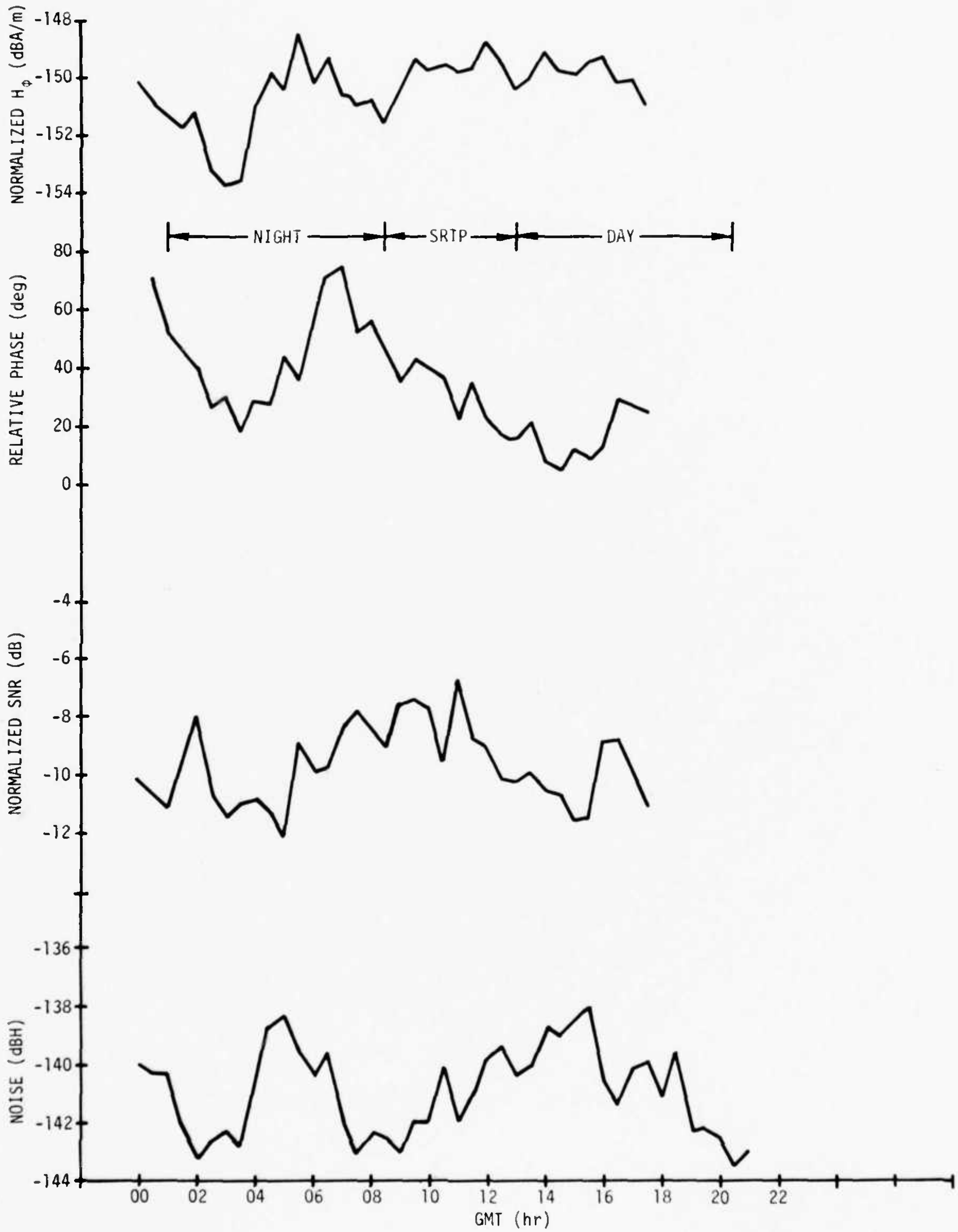

Figure A-5. Submarine Data Versus GMT (ψ = 201 deg), 5 March 1977

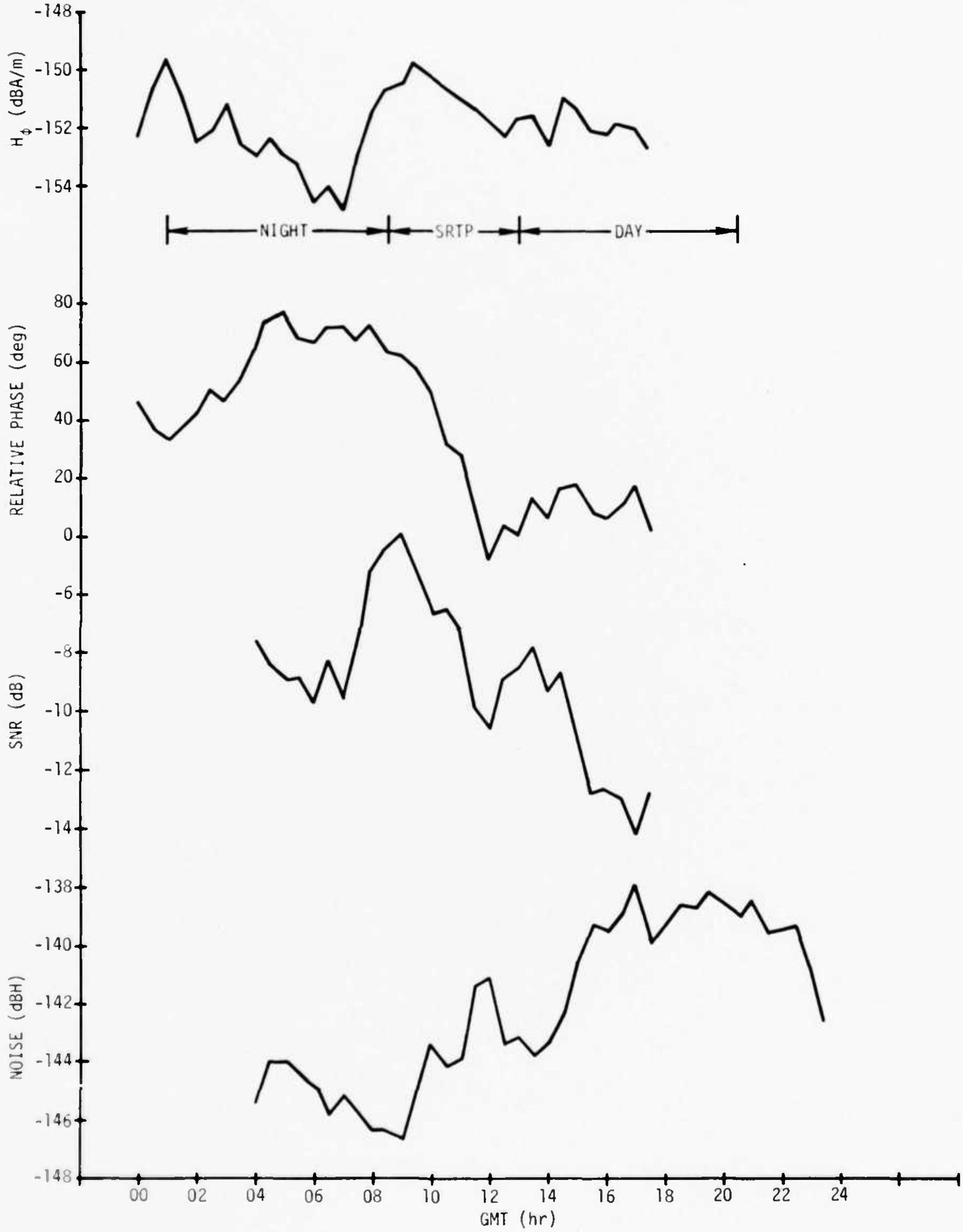

Figure A-6. Submarine Data Versus GMT
(ψ = 111 deg), 6 March 1977

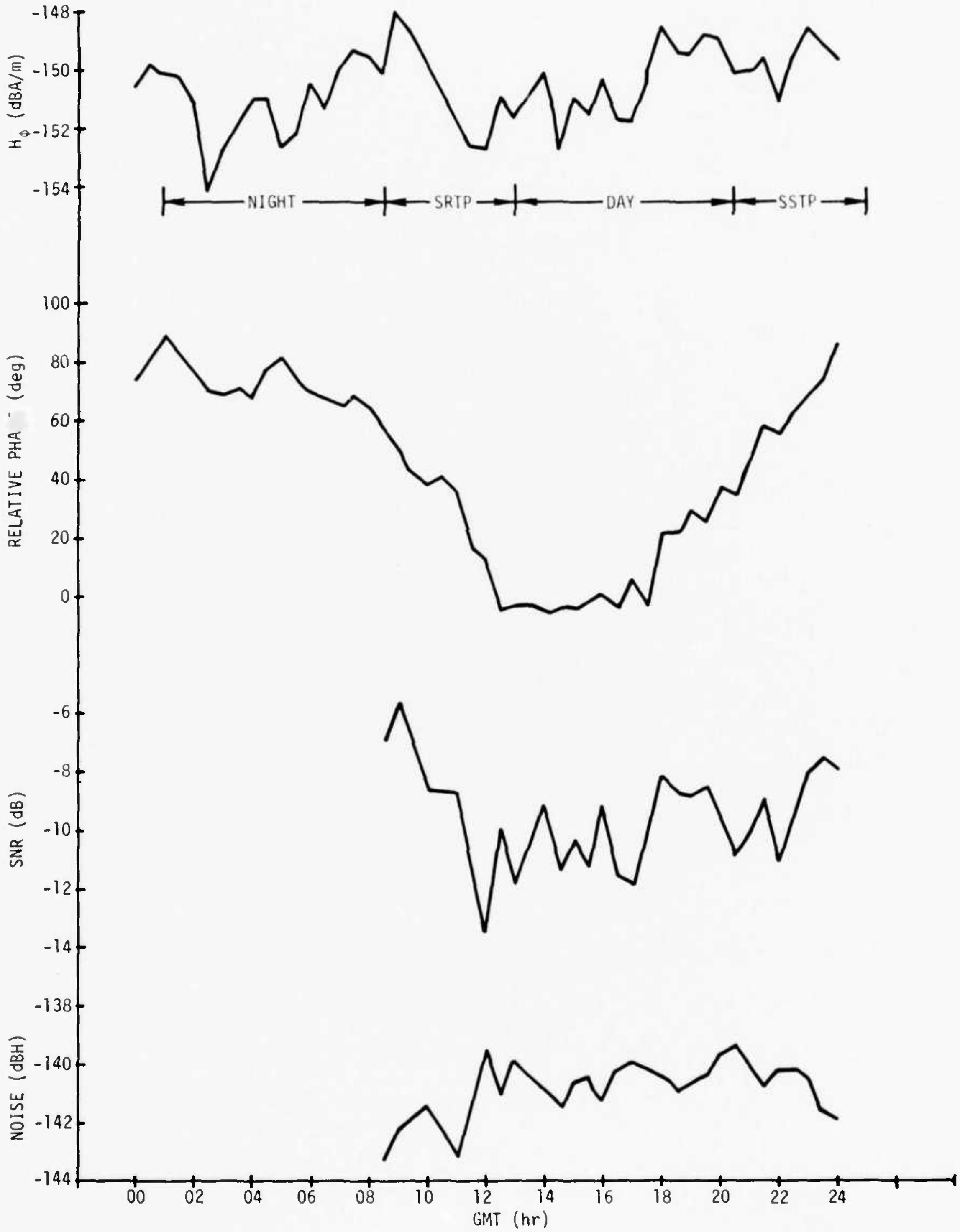

Figure A-7. Submarine Data Versus GMT
(ψ = 111 deg), 7 March 1977

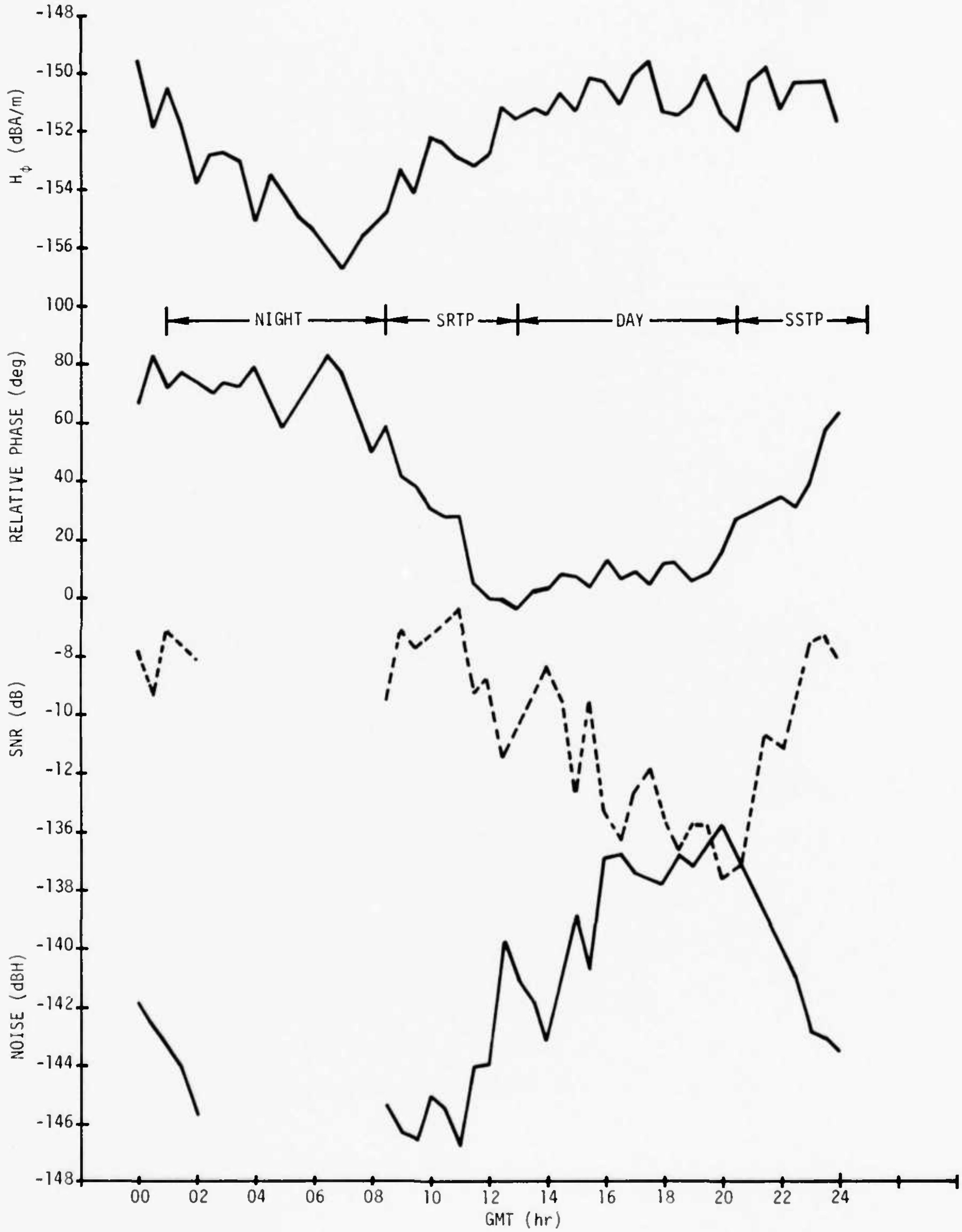

Figure A-8. Submarine Data Versus GMT
(ψ = 291 deg), 8 March 1977

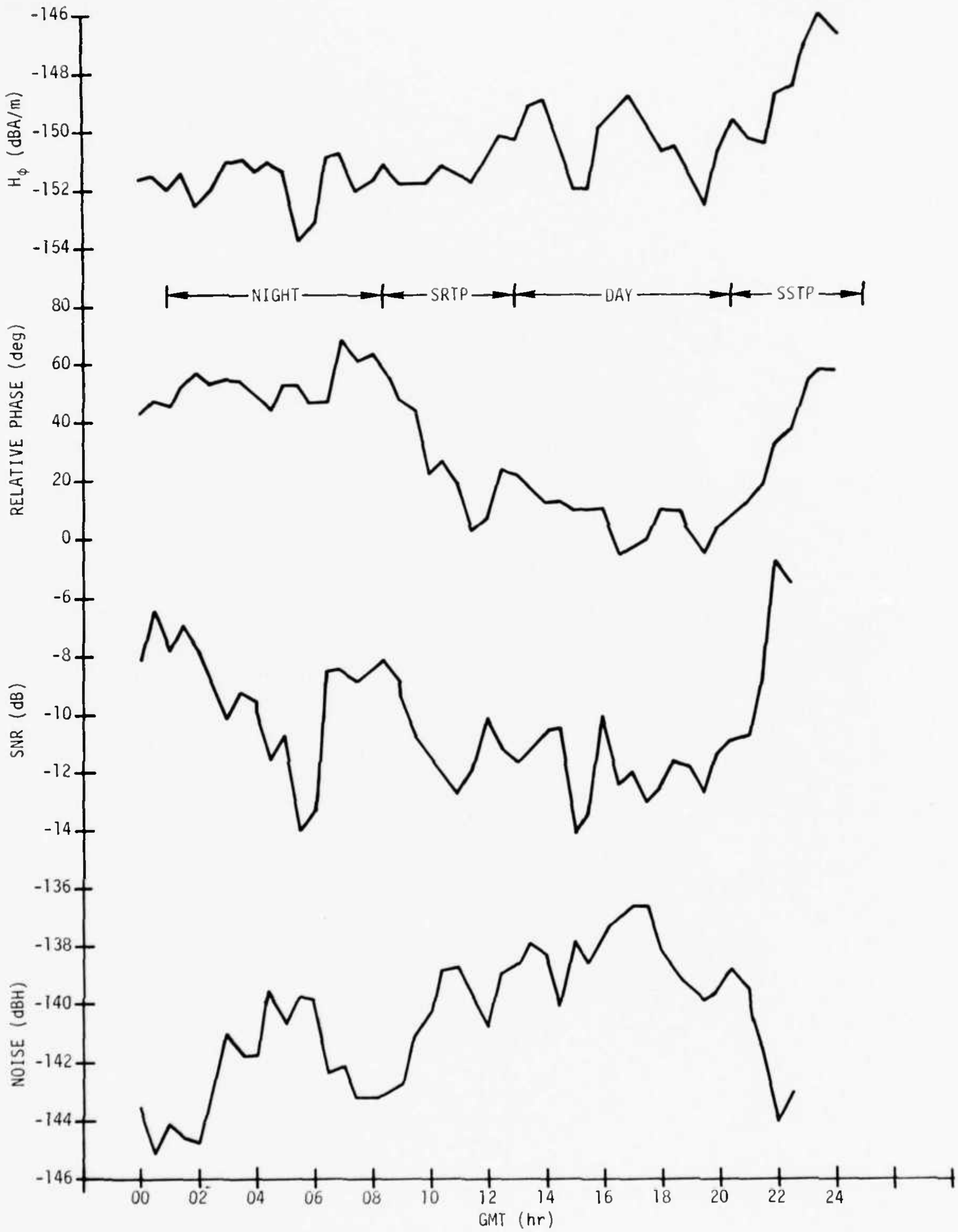

Figure A-9. Submarine Data Versus GMT
(ψ = 291 deg), 9 March 1977

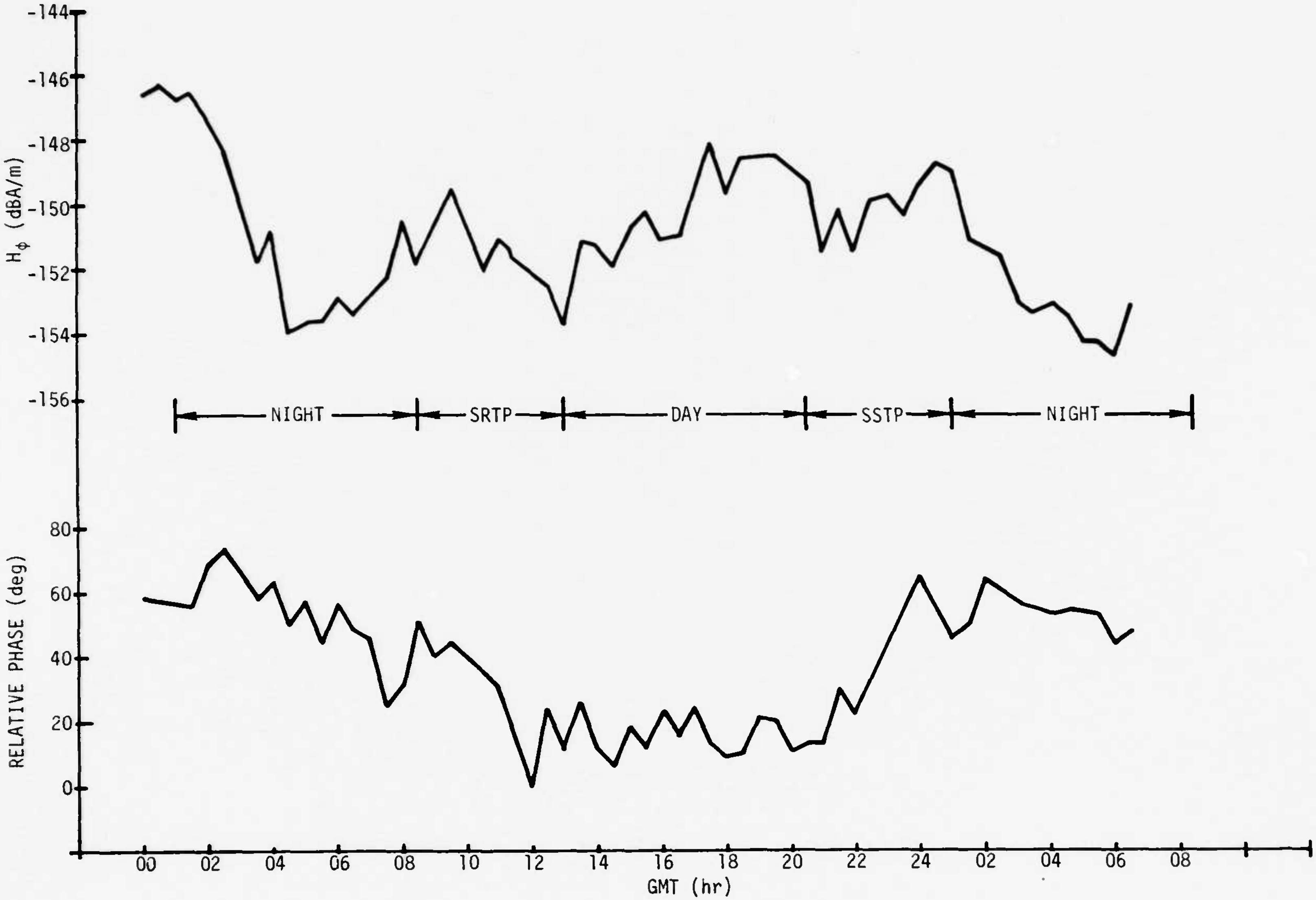

Figure A-10. Submarine Data Versus GMT (ψ = 291 deg), 10 and 11 March 1977

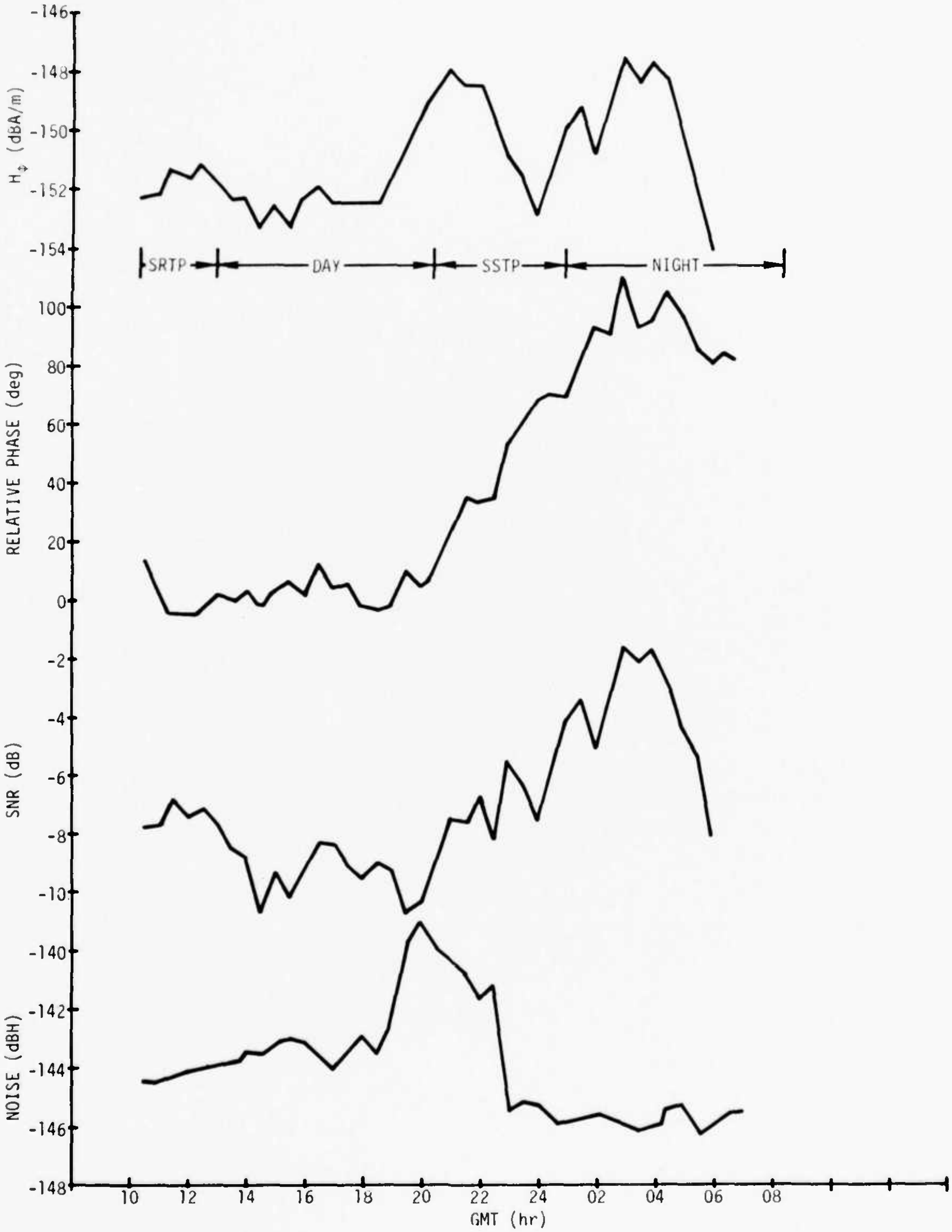

Figure A-11. Submarine Data Versus GMT
(ψ = 291 deg), 14 and 15 March 1977

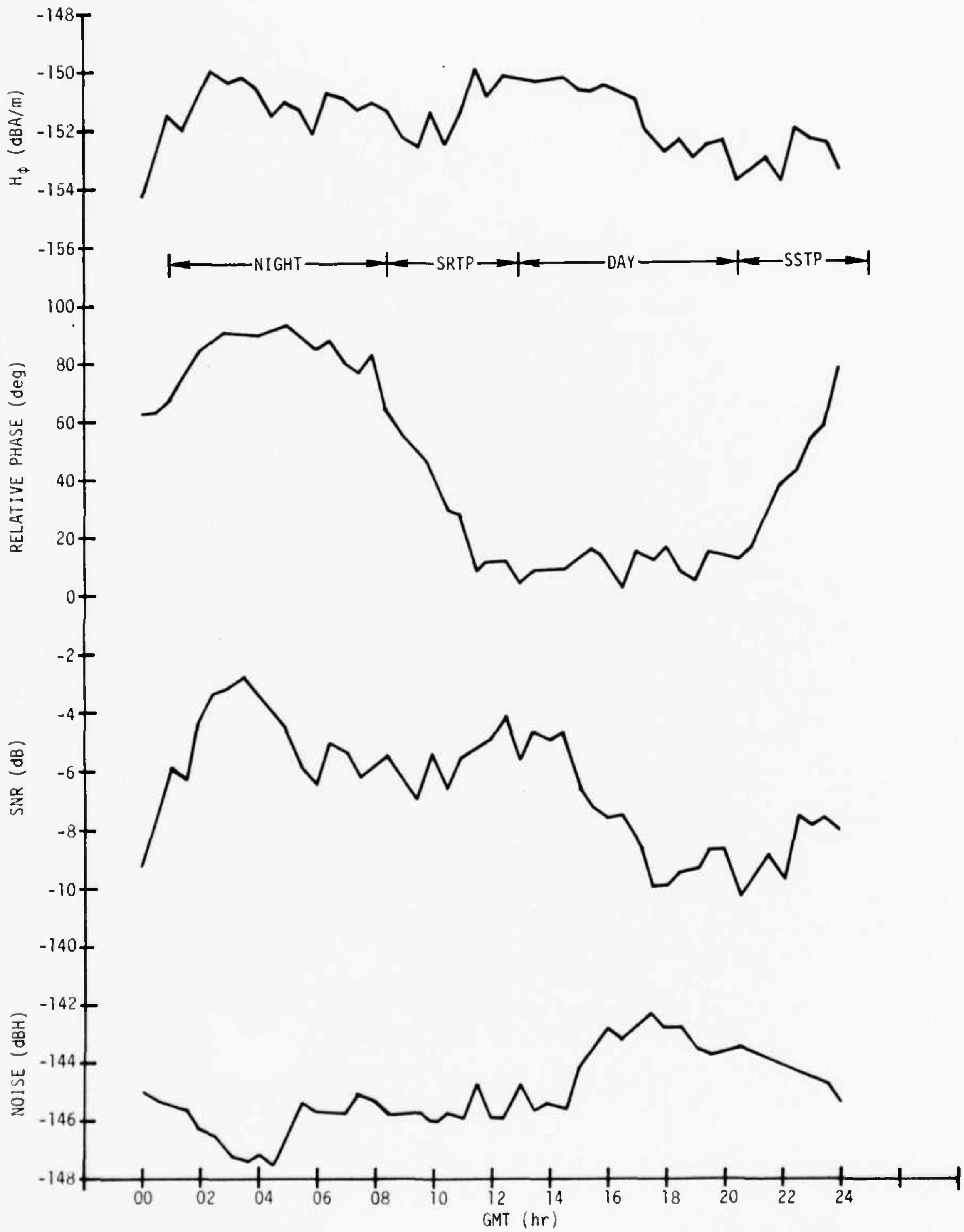

Figure A-12. Submarine Data Versus GMT
(ψ = 291 deg), 16 March 1977

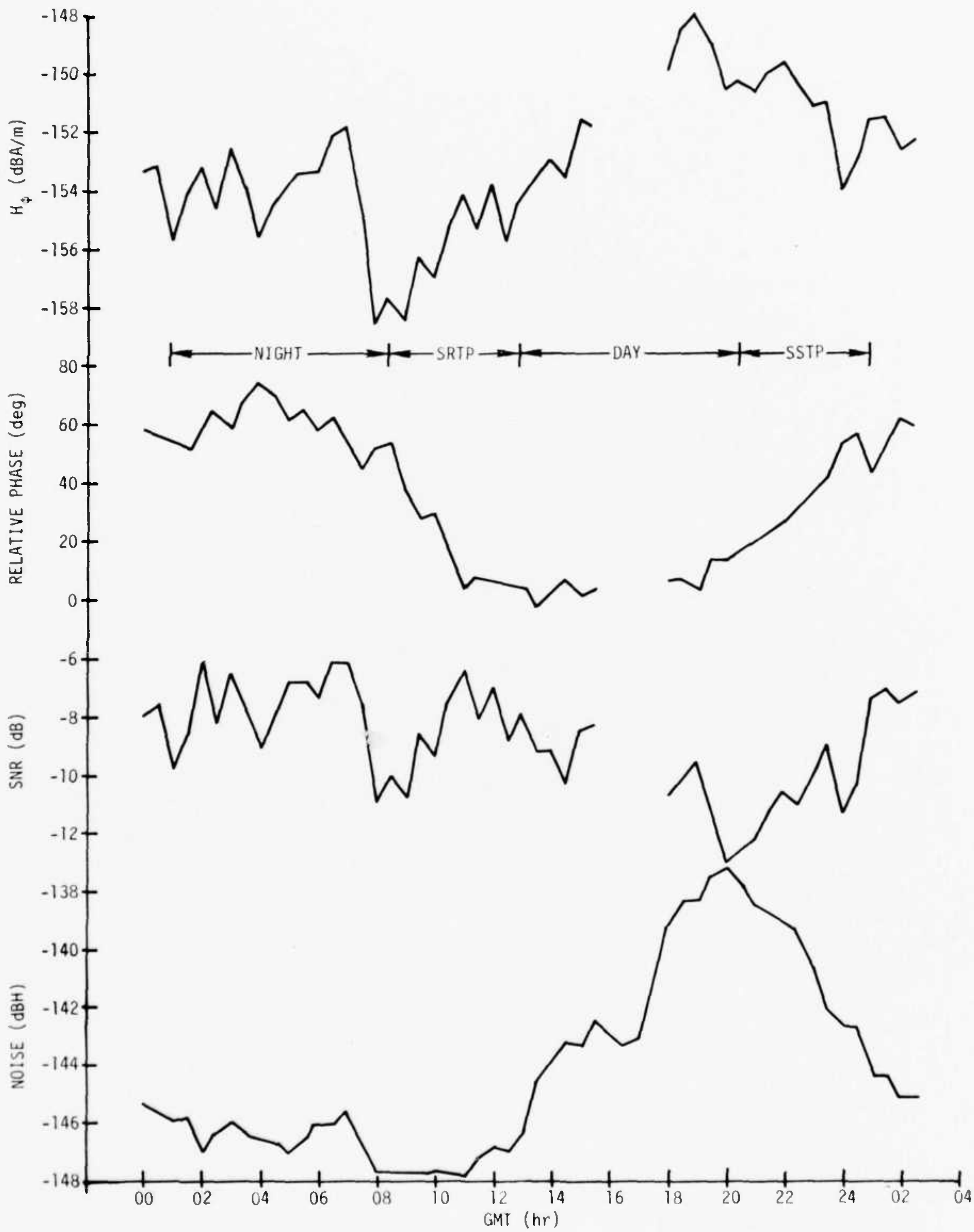

Figure A-13. Submarine Data Versus GMT (ψ = 291 deg), 17 March 1977

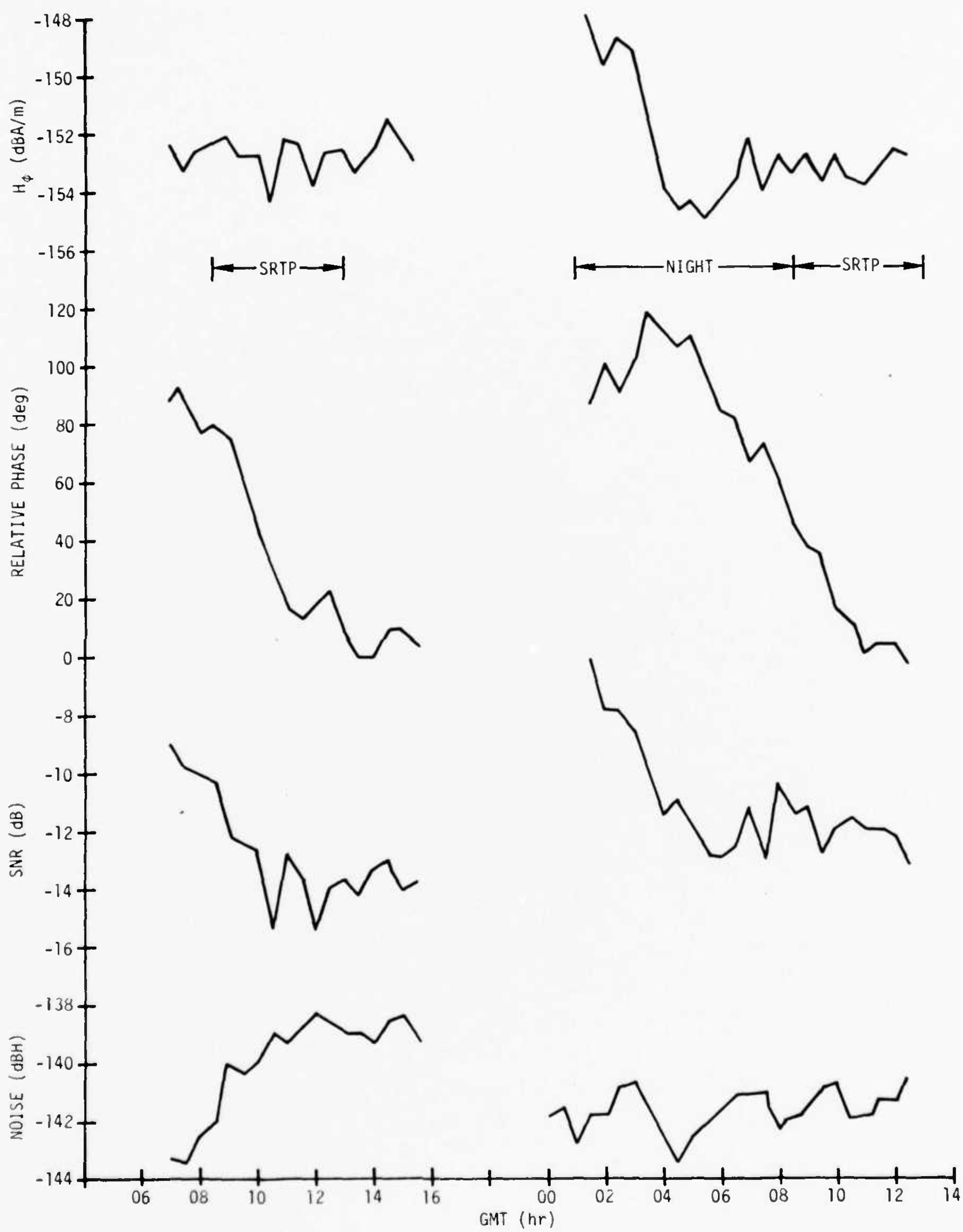

Figure A-14. Submarine Data Versus GMT
(ψ = 291 deg), 26 and 27 March 1977

Appendix B

FEBRUARY AND MARCH 1977 CONNECTICUT DAILY DATA

For the Connecticut measurements, the AN/BSR-1 receiver is located in Room 3111, Building 80, Naval Underwater Systems Center (NUSC), New London, CT. The loop receiving antenna is located at Fishers Island, NY (about 10 km from New London). The receiver and receiving antenna are connected by means of a microwave link from Fishers Island to New London. The receiving antenna is located approximately 50 m from an NUSC building at Fishers Island which houses the ELF preamplifier and associated circuitry.

As was previously mentioned,* the Connecticut effective-noise measurements are sometimes contaminated by industrial noise. Thus, the effective-noise values presented in this appendix are on the high side.

The March daily field-strength (both amplitude and relative phase), effective-noise, and SNR values are plotted versus GMT in this appendix. For comparison purposes, the February Connecticut data are also included.

The February data are plotted versus GMT in figures B-1 through B-23. Amplitude peak-to-trough variations of 5 dB or greater occurred on only 4 of the first 18 measurement days (2/2, 2/3, 2/5, and 2/12). However, during the last 10 days, the amplitude peak-to-trough variation was greater than 5 dB during 6 of the 10 days. The largest variation (7.4 dB) occurred on 22 February (figure B-17).

The February night-to-day relative-phase variation was 26 ±9 deg, which was about the same $\Delta\phi$ variation measured during the last two weeks in January* (25 ±8 deg). The largest relative-phase variation (36 deg) occurred on 27 and 28 February (figures B-22 and B-23), while the smallest (12 deg) occurred on 7 February (figure B-6).

The March data are plotted versus GMT in figures B-24 through B-52. Amplitude peak-to-trough variations of 5 dB or greater occurred during 14 of the 29 measurement days (3/1 to 3/5, 3/10, 3/16 to 3/19, 3/21, 3/25, 3/28, and 3/30). The largest variation (7.5 dB) occurred on 3 and 4 March (figures B-25 to B-27).

The March night-to-day relative-phase variation was 29 ±7 deg, with the largest (36 deg) measured on 2 March (figure B-24) and the smallest (23 deg) measured on 11 March (figure B-34).

A comparison of the early February (figures B-1 through B-14) and March (figures B-24 through B-52) plots reveals that the March nighttime field strengths were much more variable than the early February nighttime field

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*P. R. Bannister, ELF PVS Field Strength Measurements, January 1977, NUSC Technical Report , Naval Underwater Systems Center, New London, CT (to be published).

strengths in both amplitude and relative phase. In fact, the number of March measurement days where the amplitude peak-to-trough variations were 5 dB or greater (14) were the most per month that we have measured in Connecticut.

Some additional examples of the variability (in both amplitude and relative phase) of the Connecticut nighttime field strength are presented in figures B-53 through B-56. An expanded scale has been employed in plotting these figures (i.e., 1 dB per division and 10 deg per division rather than the usual 2 dB per division and 20 deg per division). These data are characterized by:

1. Substantial amplitude decreases and relative-phase increases during the nighttime period of 0400 to 0800;

2. Substantial amplitude increases and relative-phase decreases (and, then, increases) near the end of the nighttime measurement period and the beginning of sunrise transition period; and

3. Amplitude peaks around the beginning of the daytime propagation period.

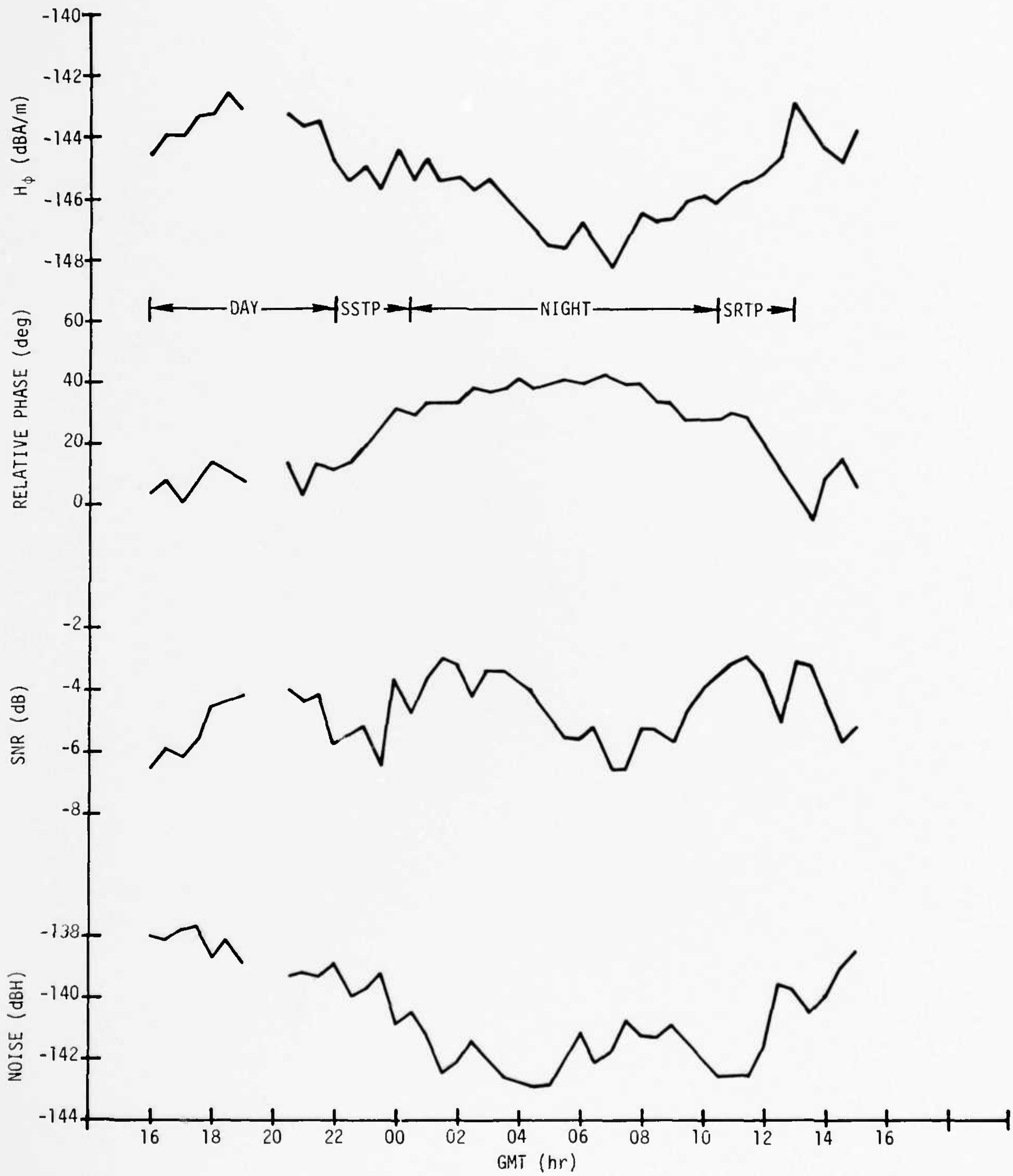


Figure B-1. Connecticut Data Versus GMT (ψ = 204 deg), 1 and 2 February 1977

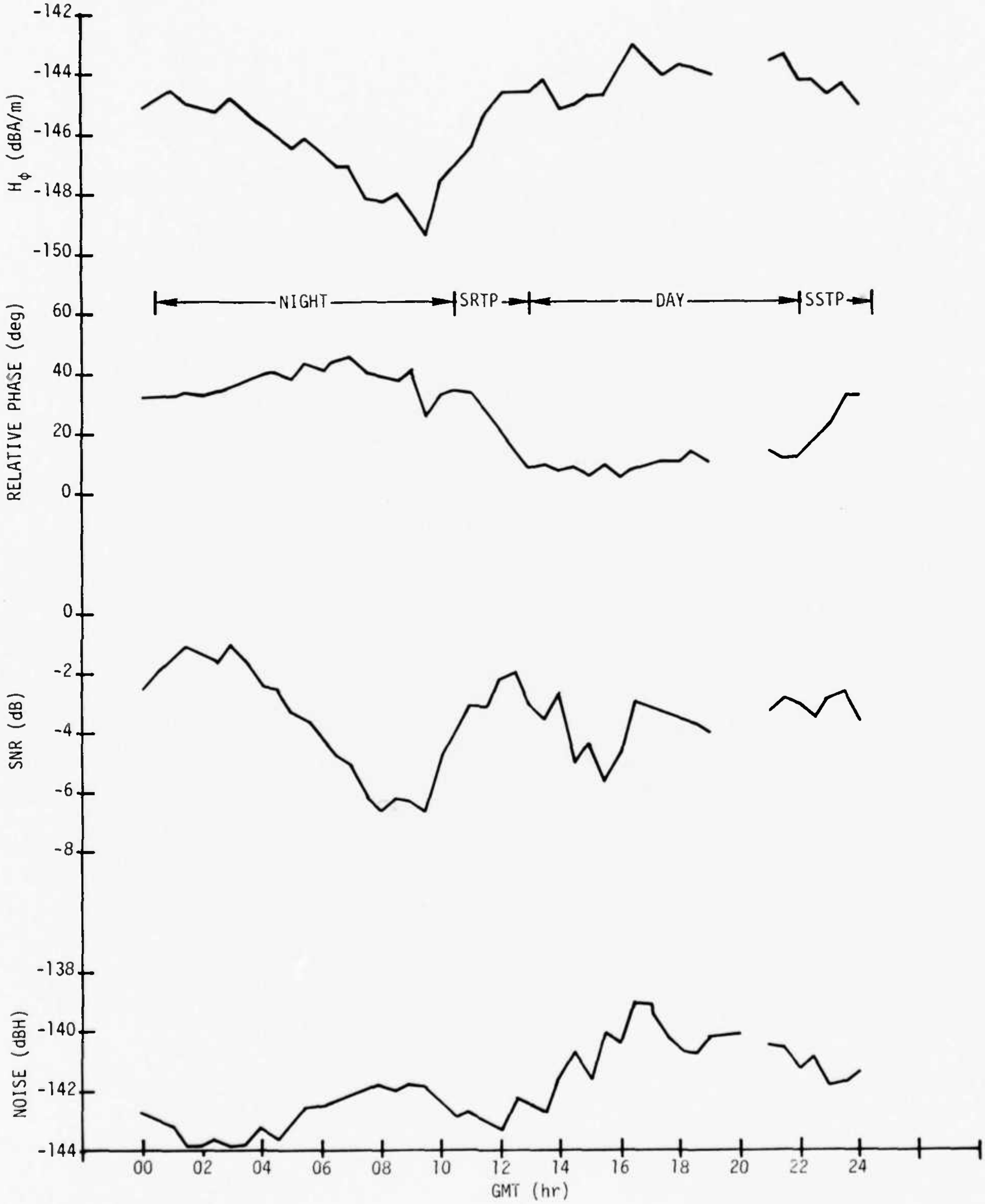


Figure B-2. Connecticut Data Versus GMT
(ψ = 204 deg), 3 February 1977

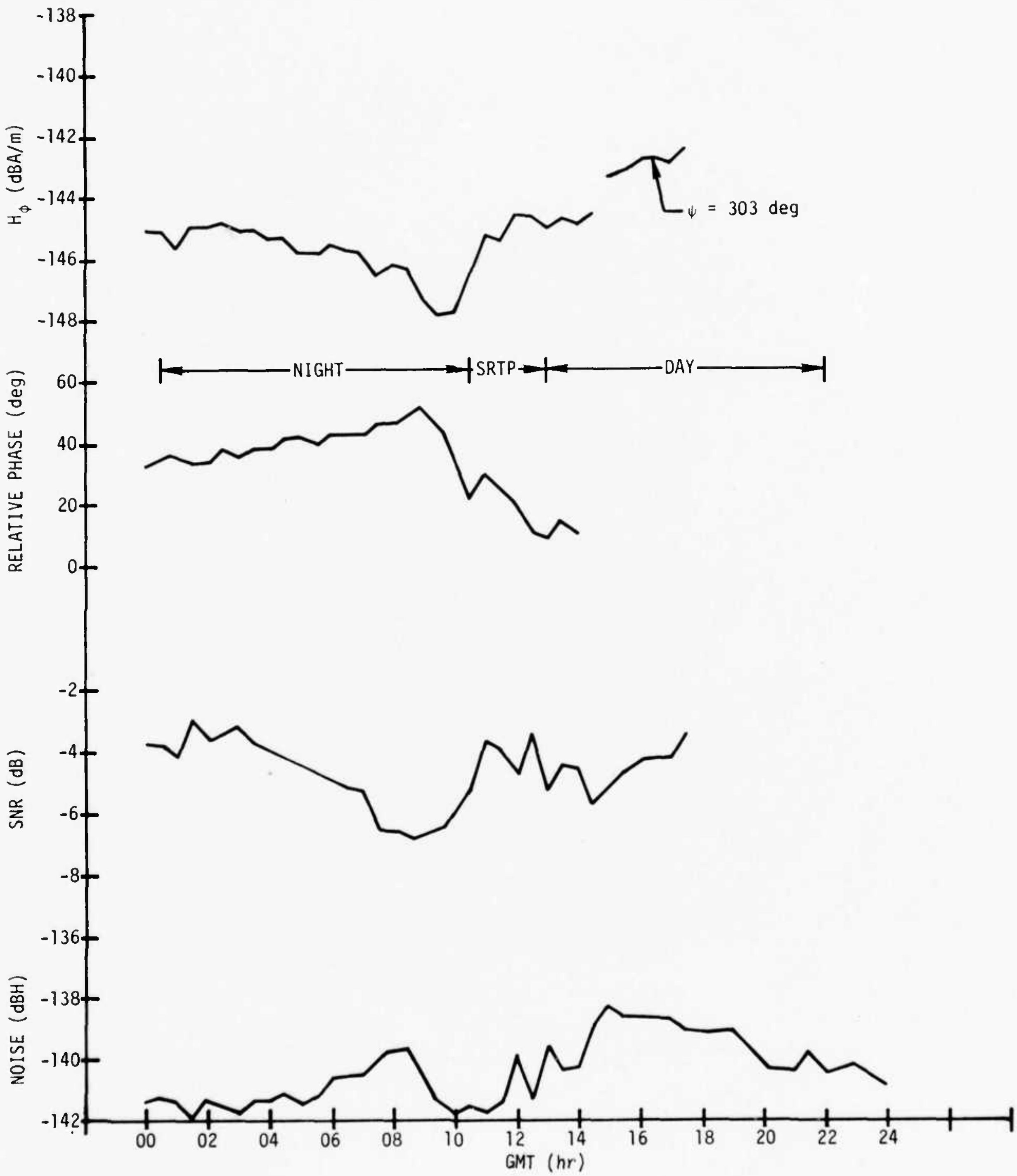


Figure B-3. Connecticut Data Versus GMT (ψ = 204 deg), 4 February 1977

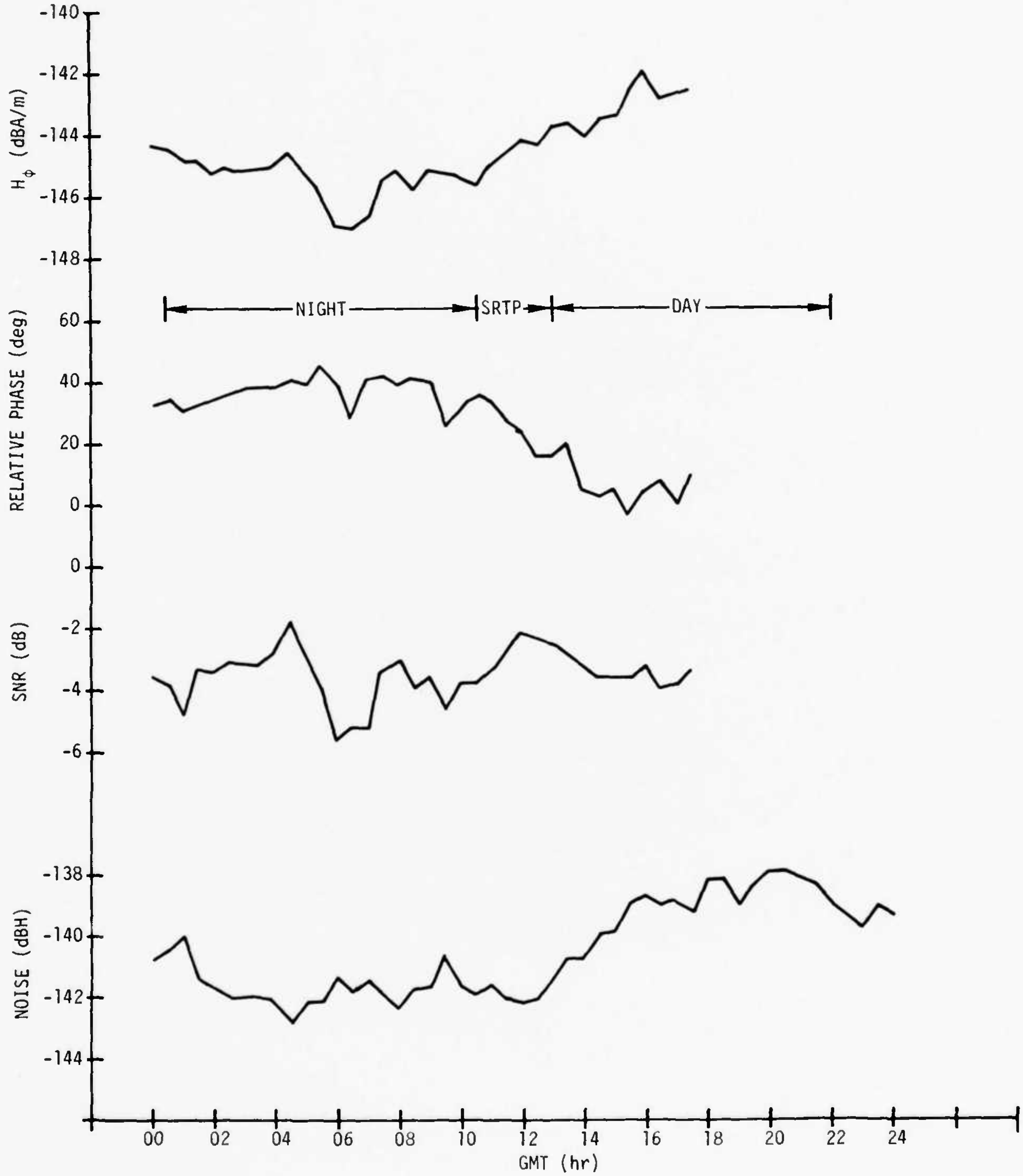


Figure B-4. Connecticut Data Versus GMT
(ψ = 303 deg), 5 February 1977

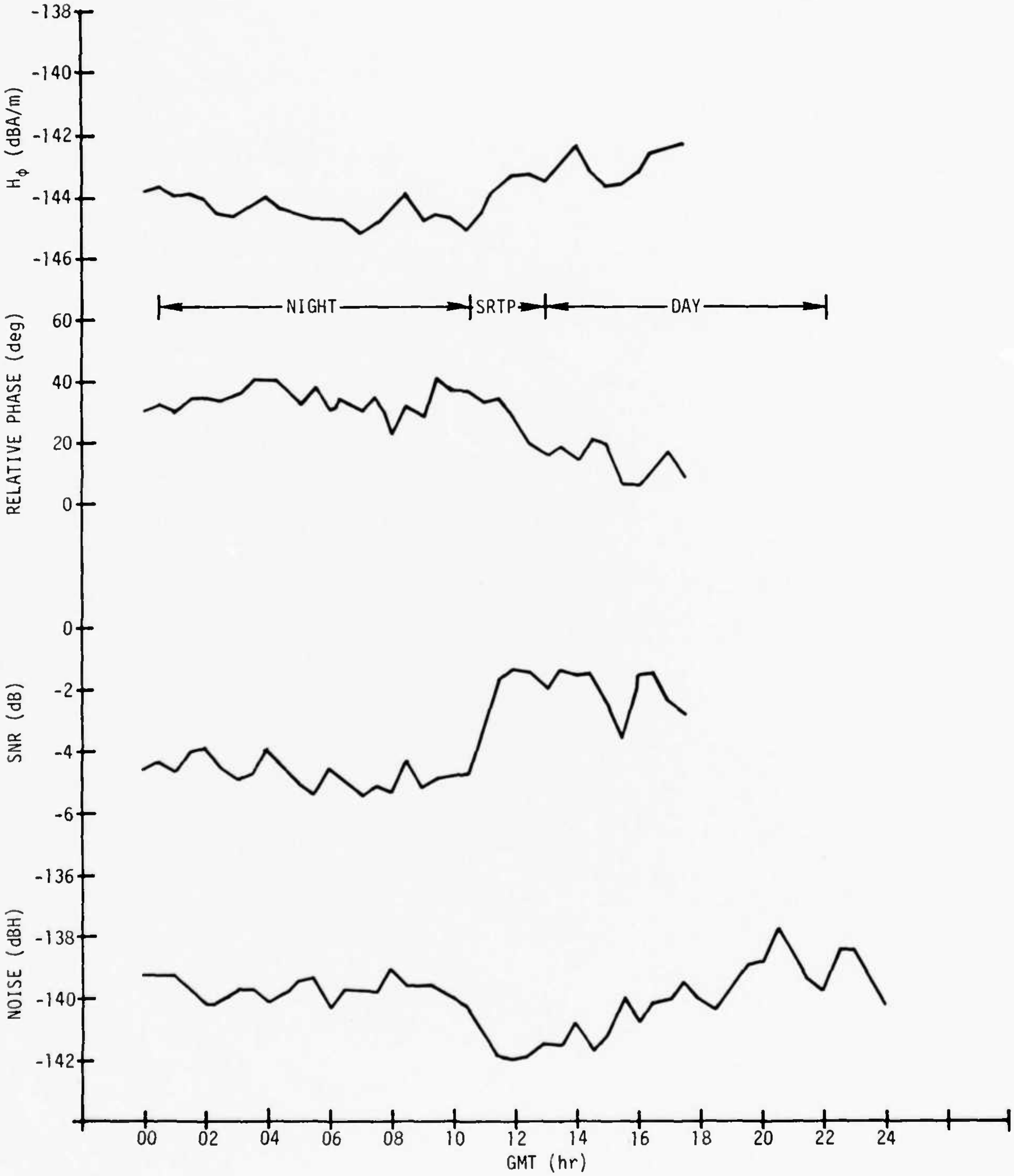


Figure B-5. Connecticut Data Versus GMT
(ψ = 303 deg), 6 February 1977

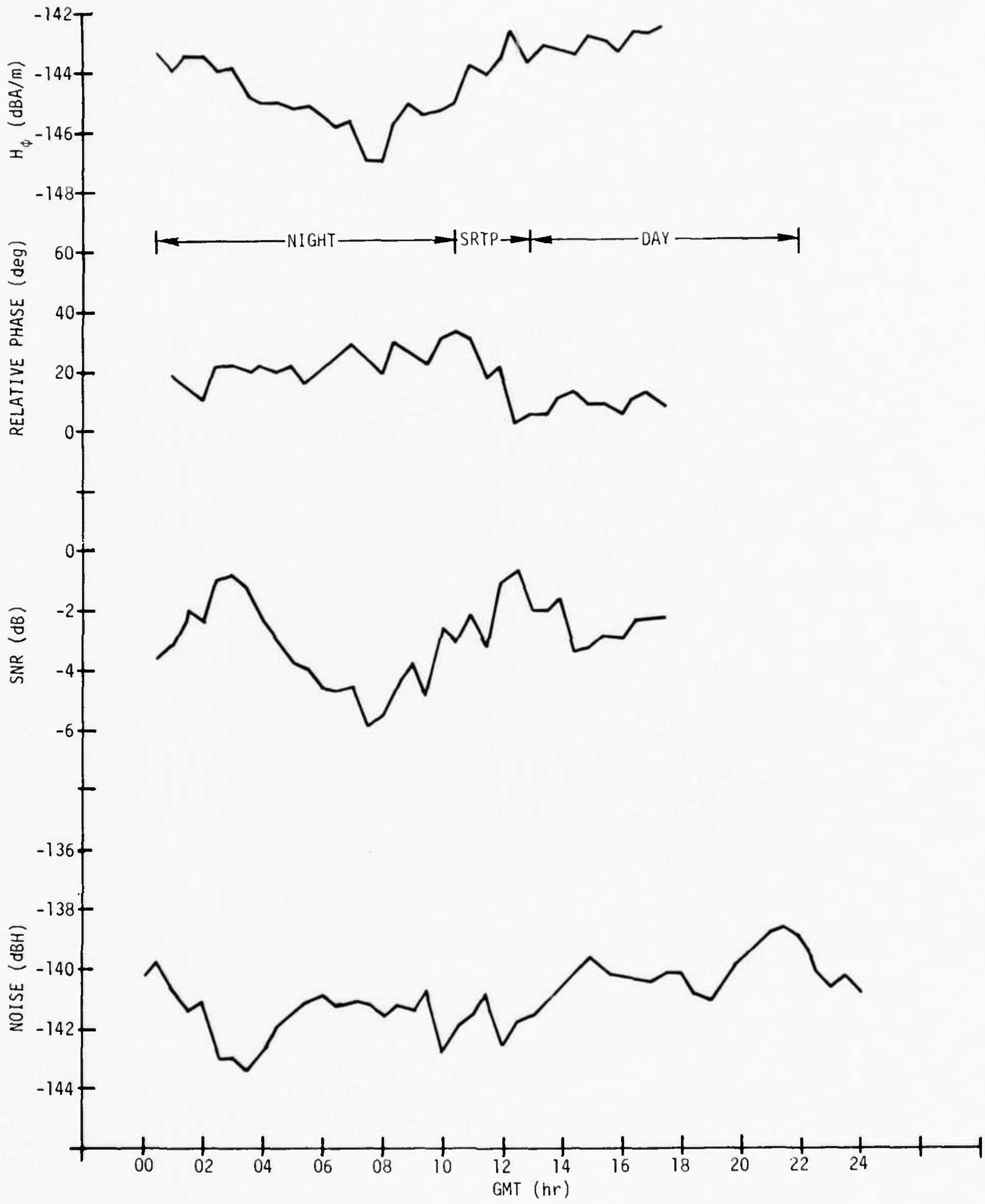


Figure B-6. Connecticut Data Versus GMT
(ψ = 303 deg), 7 February 1977

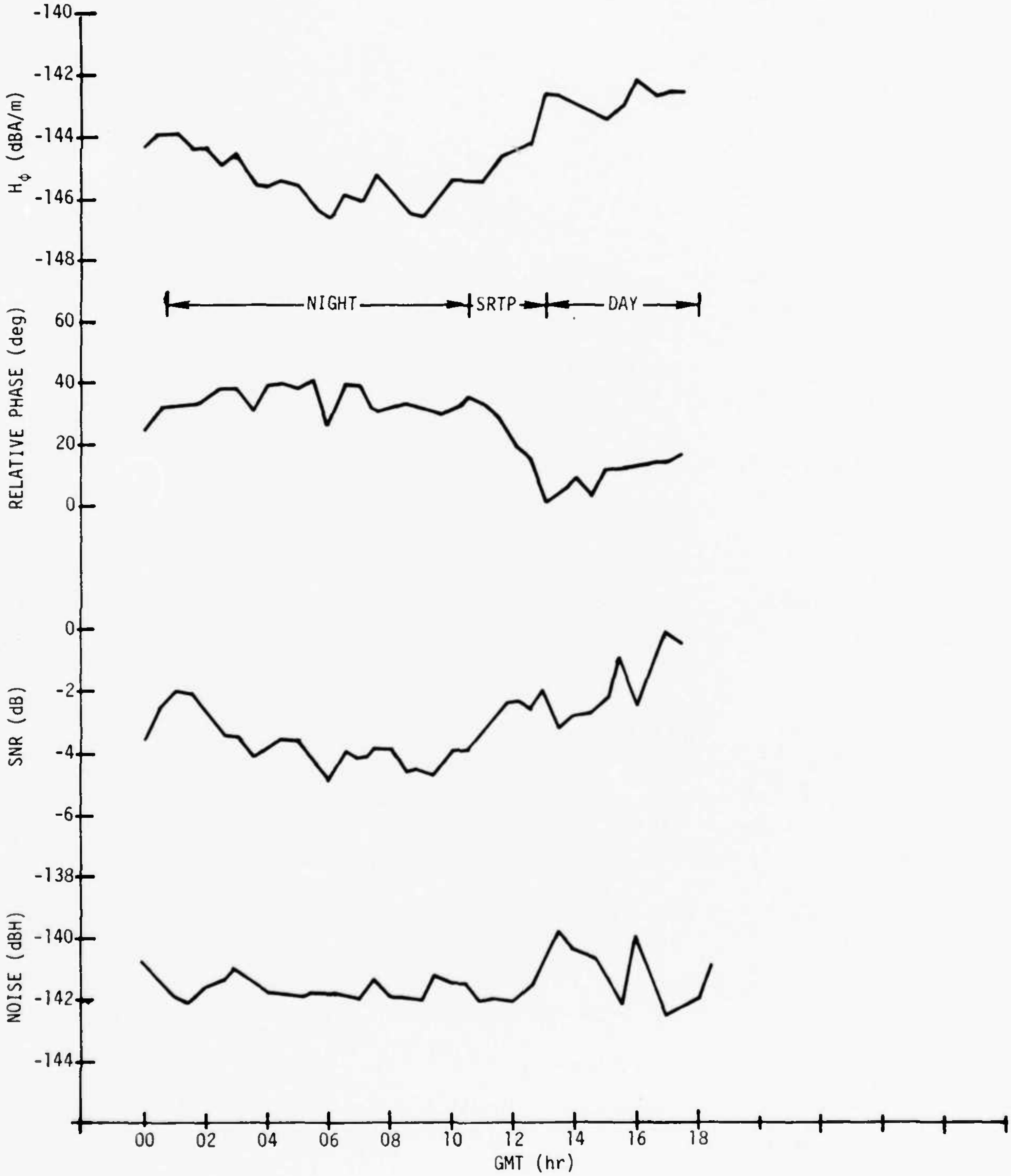


Figure B-7. Connecticut Data Versus GMT (ψ = 303 deg), 8 February 1977

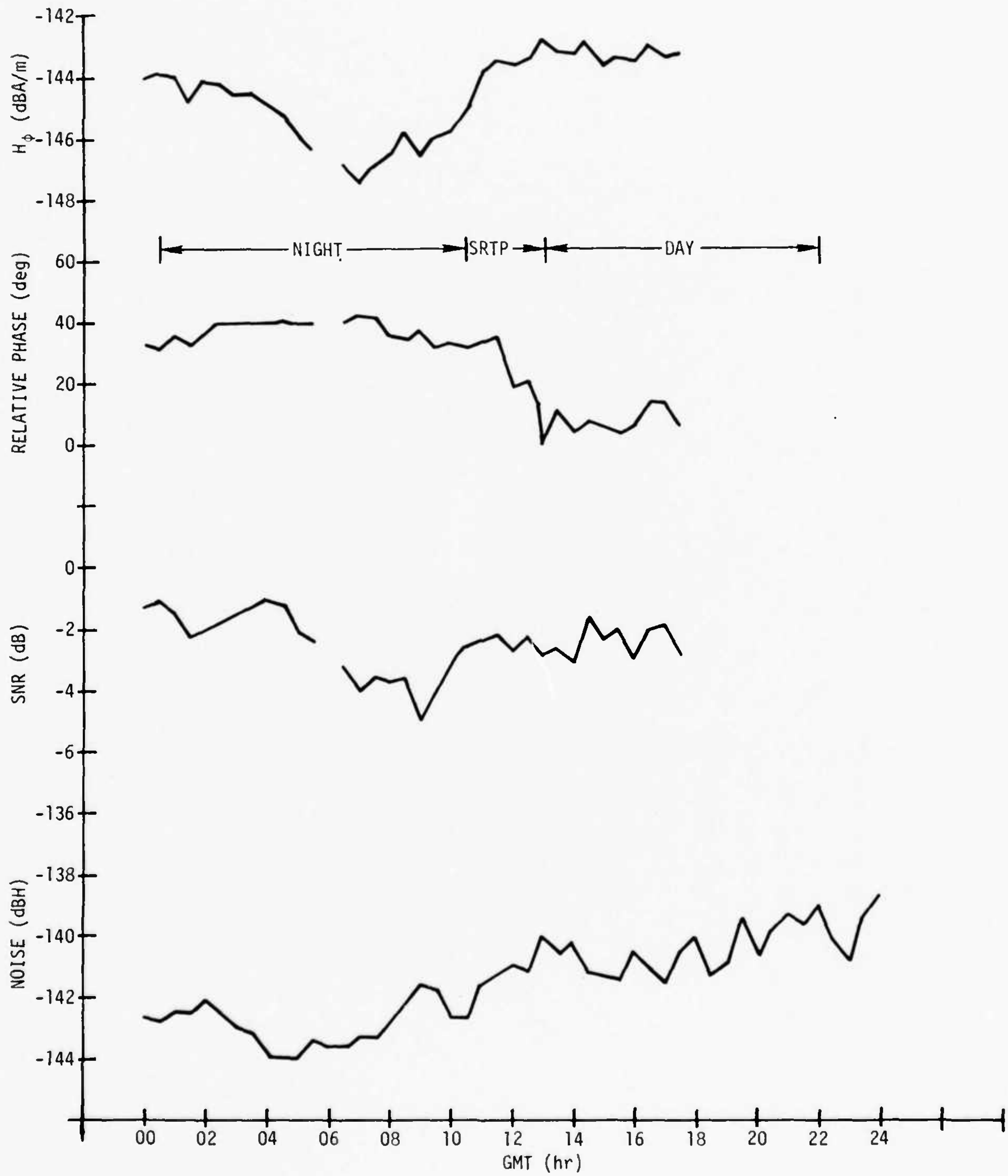


Figure B-8. Connecticut Data Versus GMT
(ψ = 303 deg), 9 February 1977

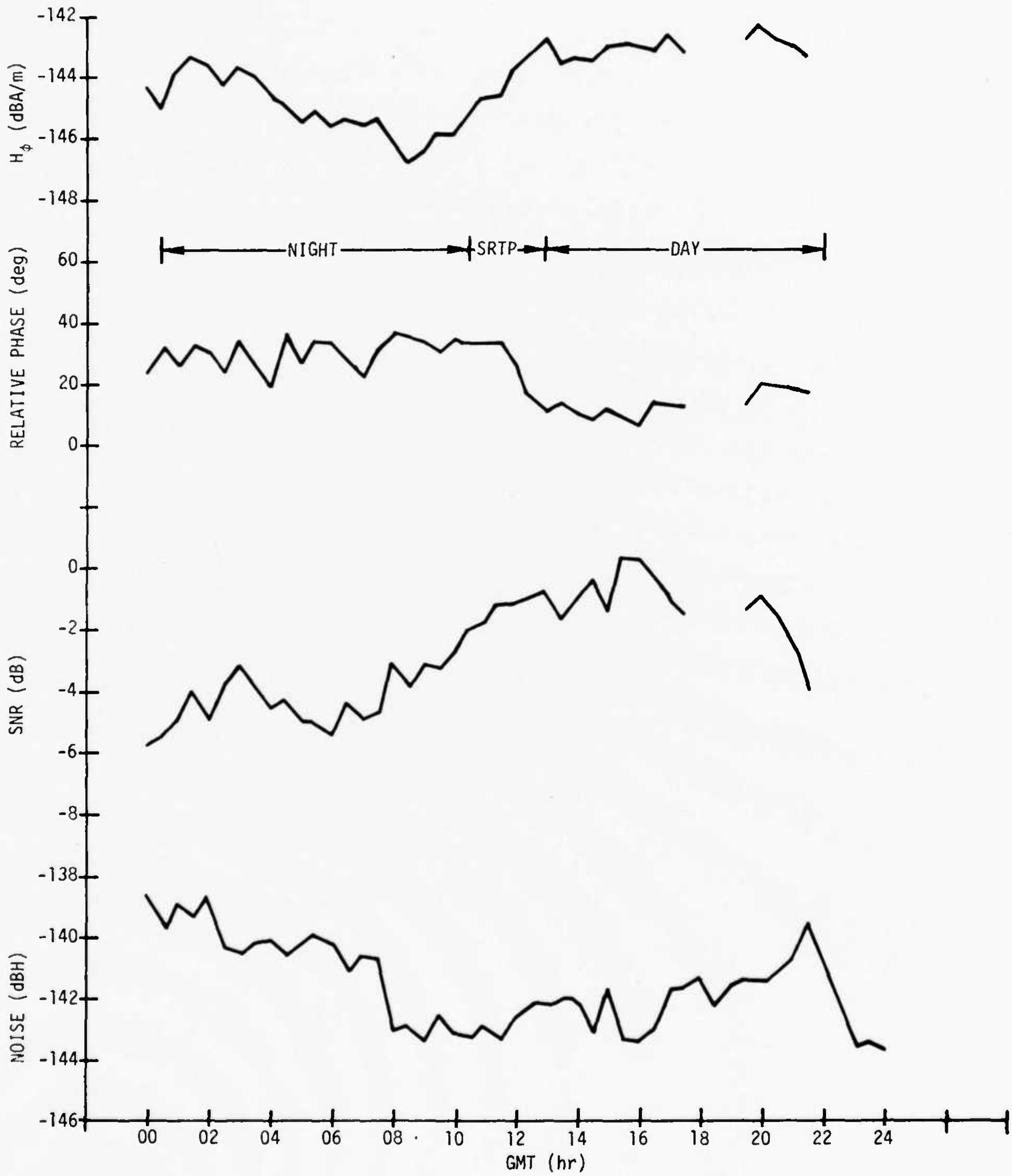


Figure B-9. Connecticut Data Versus GMT (ψ = 303 deg), 10 February 1977

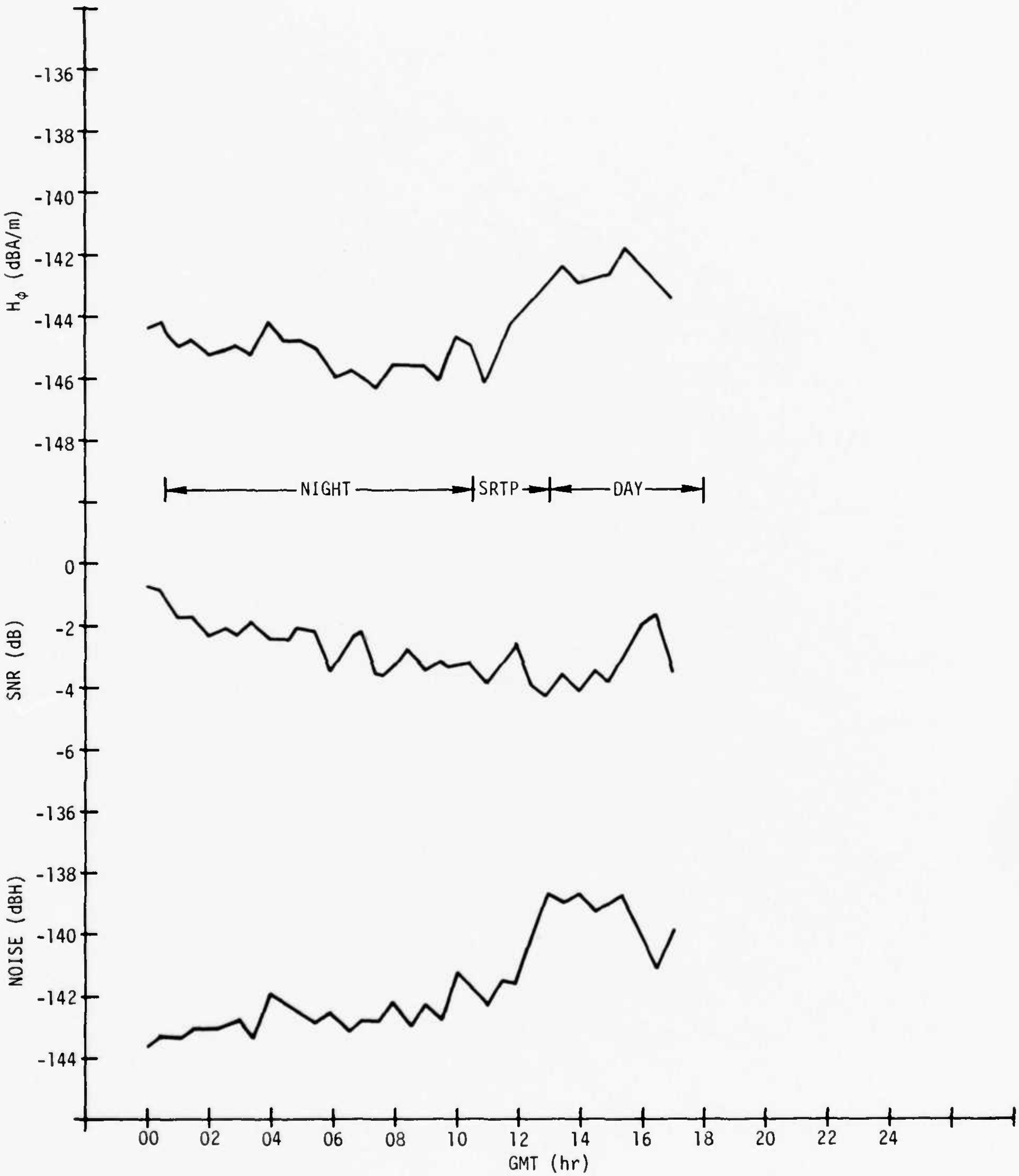


Figure B-10. Connecticut Data Versus GMT
(ψ = 303 deg), 11 February 1977

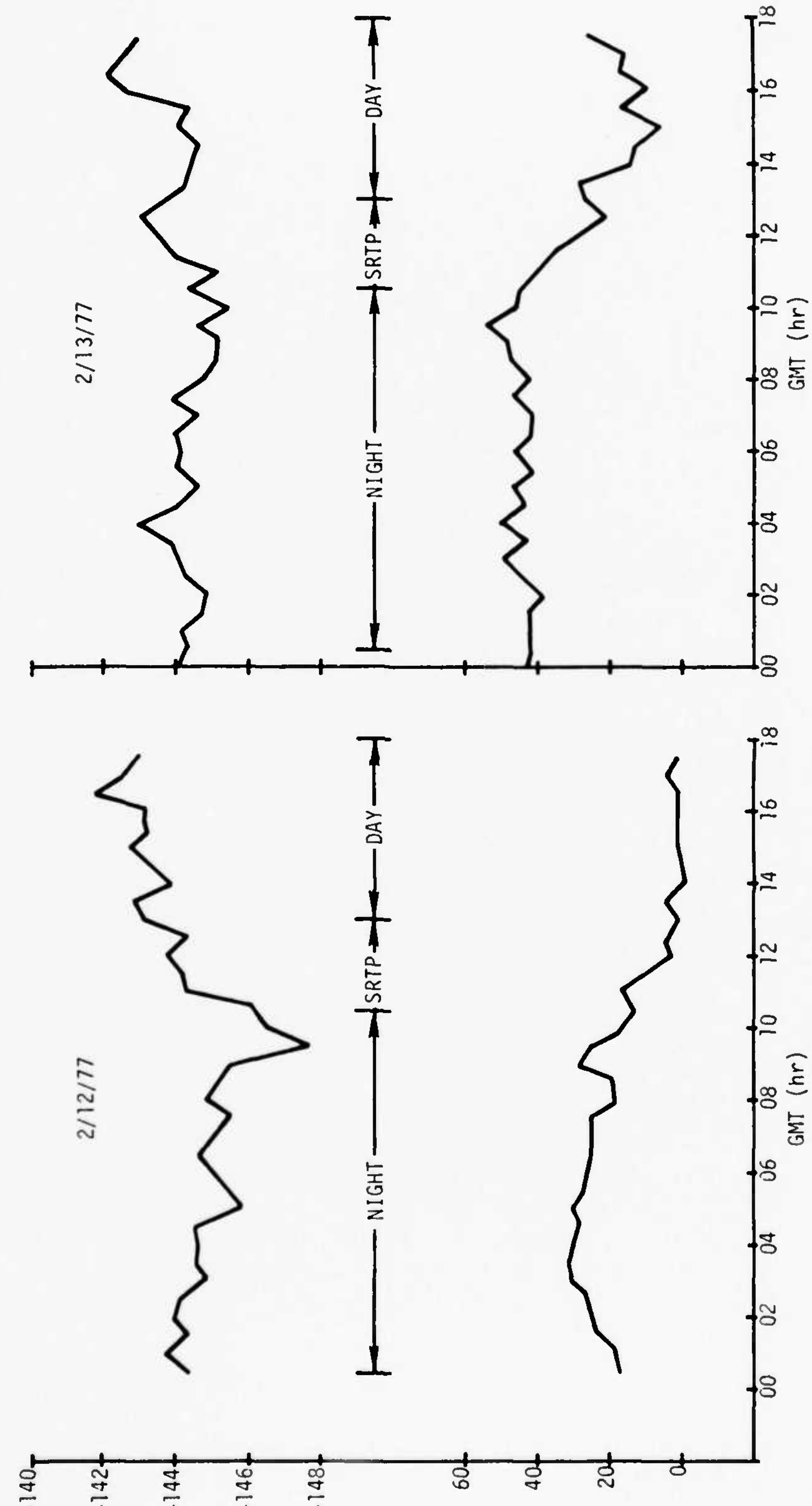


Figure B-11. Connecticut Data Versus GMT (ψ = 303 deg), 12 and 13 February 1977

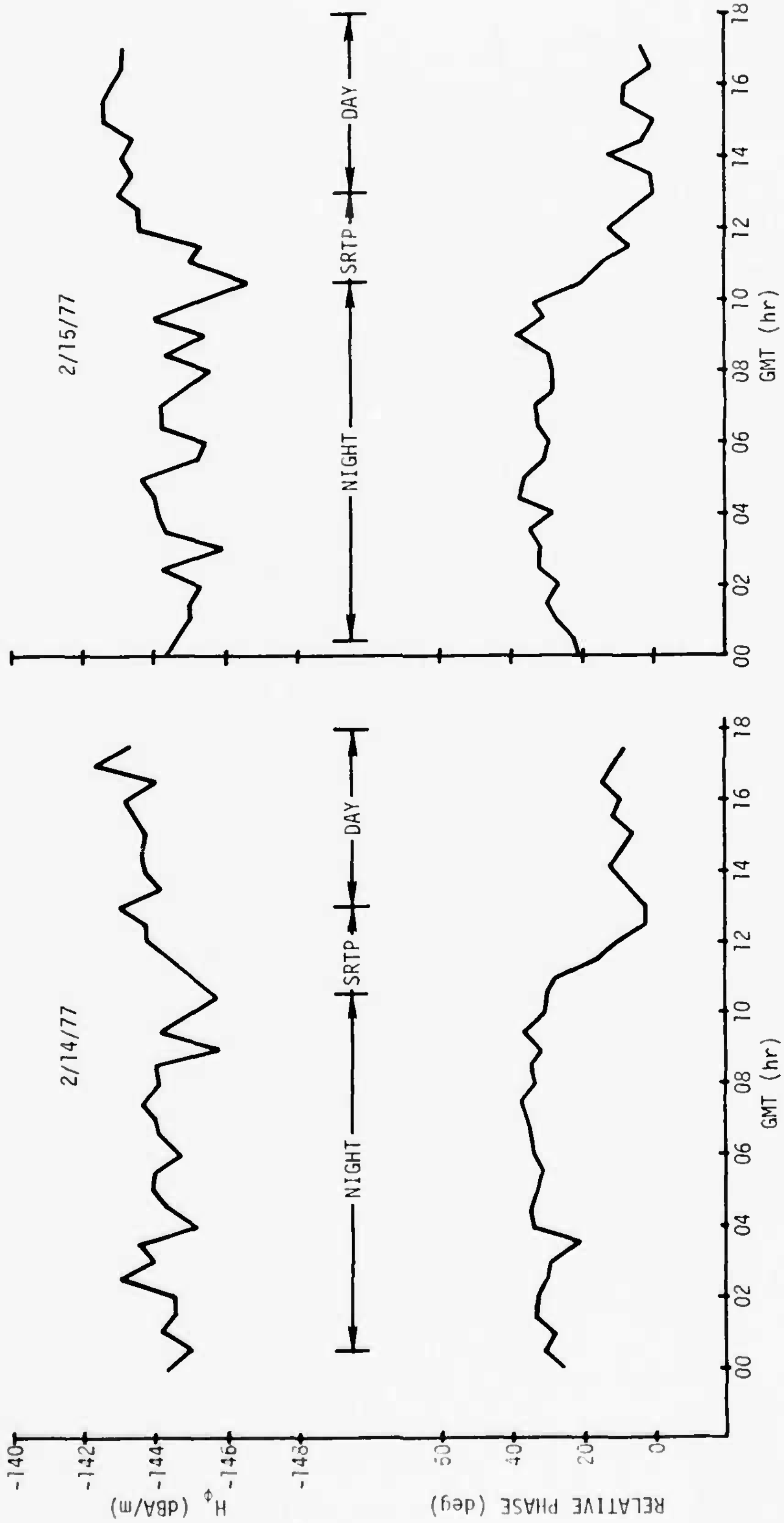


Figure B-12. Connecticut Data Versus GMT (ψ = 303 deg), 14 and 15 February 1977

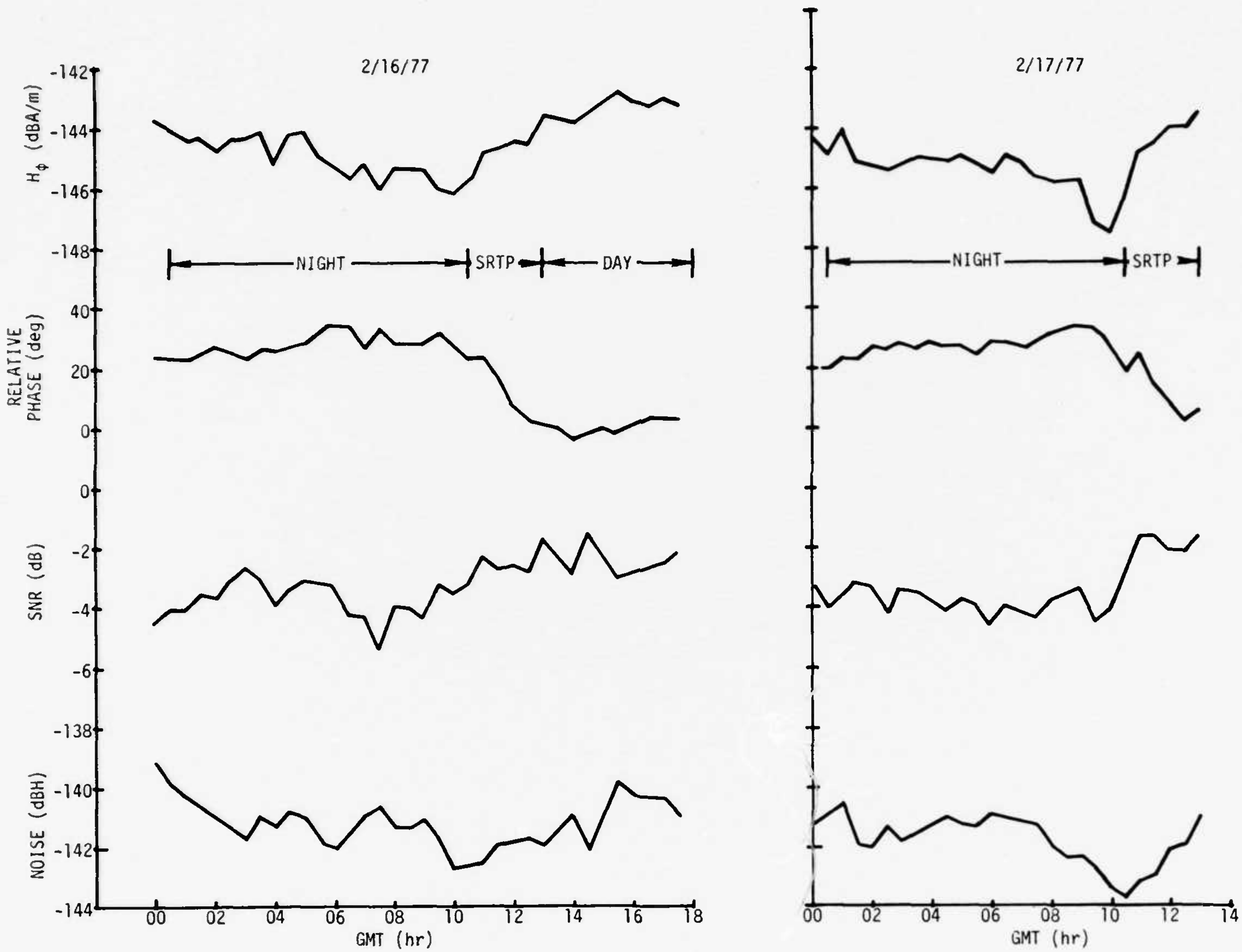


Figure B-13. Connecticut Data Versus GMT (ψ = 303 deg), 16 and 17 February 1977

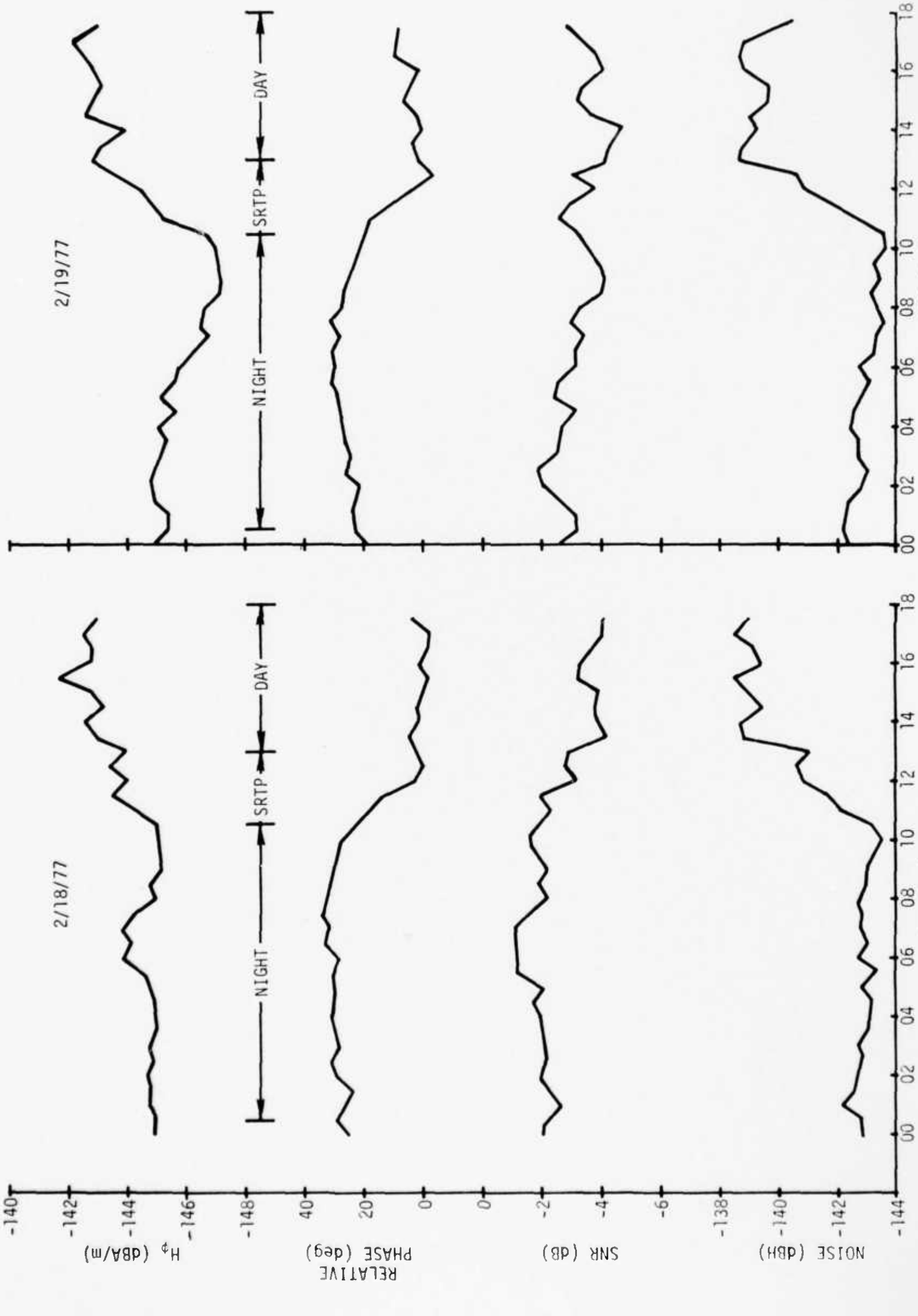


Figure B-14. Connecticut Data Versus GMT (ψ = 303 deg), 18 and 19 February 1977

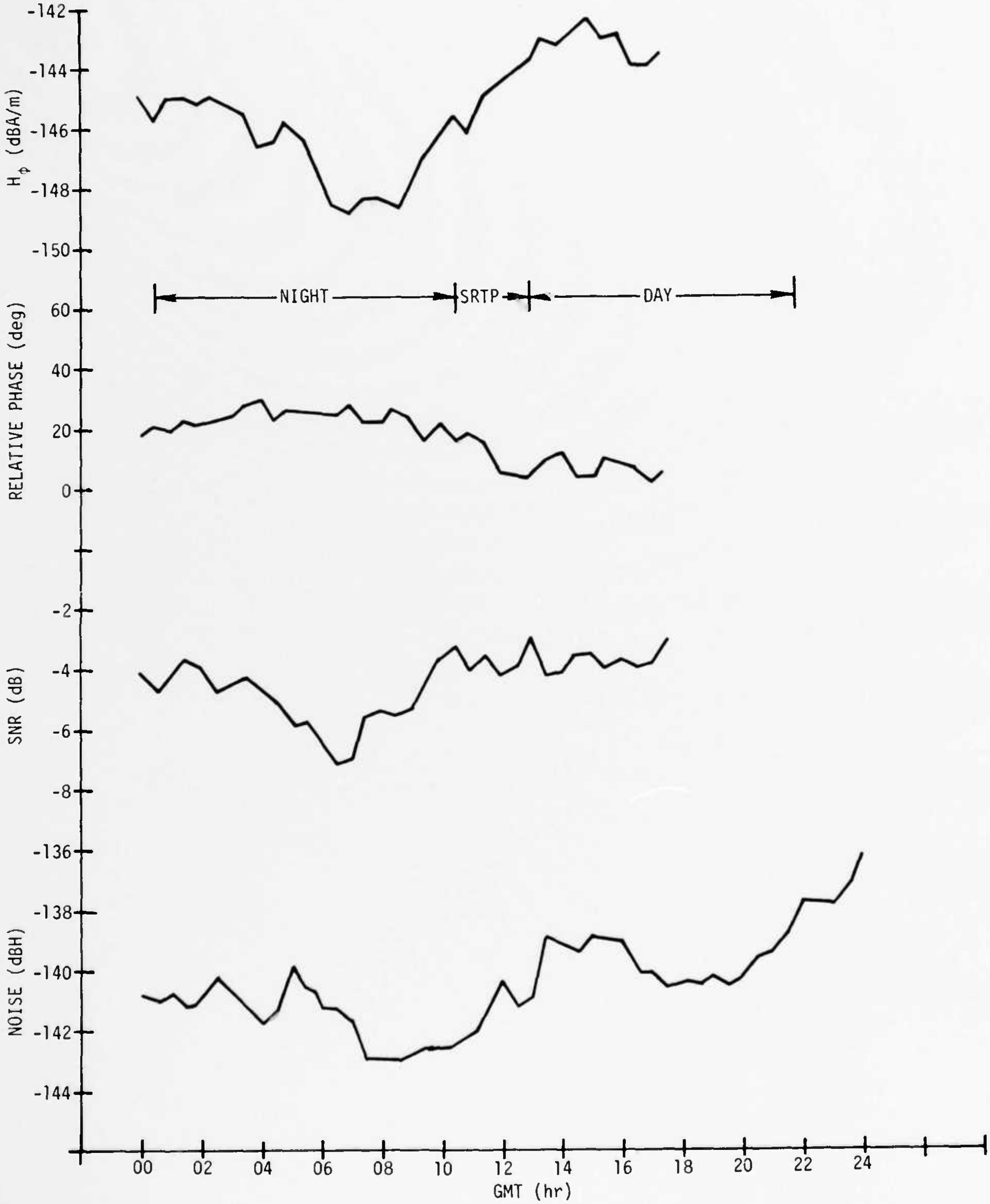


Figure B-15. Connecticut Data Versus GMT
(ψ = 303 deg), 20 February 1977

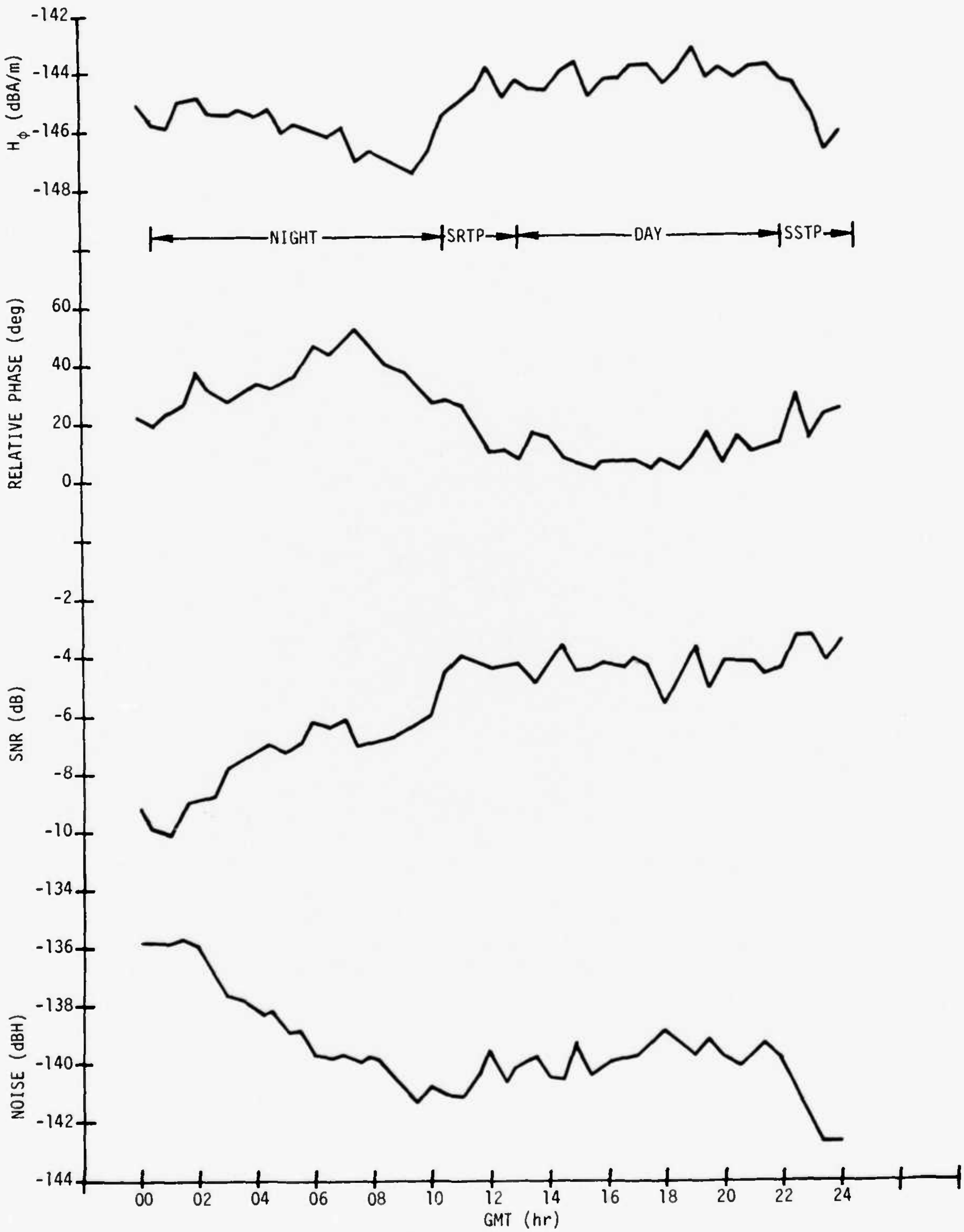


Figure B-16. Connecticut Data Versus GMT (ψ = 204 deg), 21 February 1977

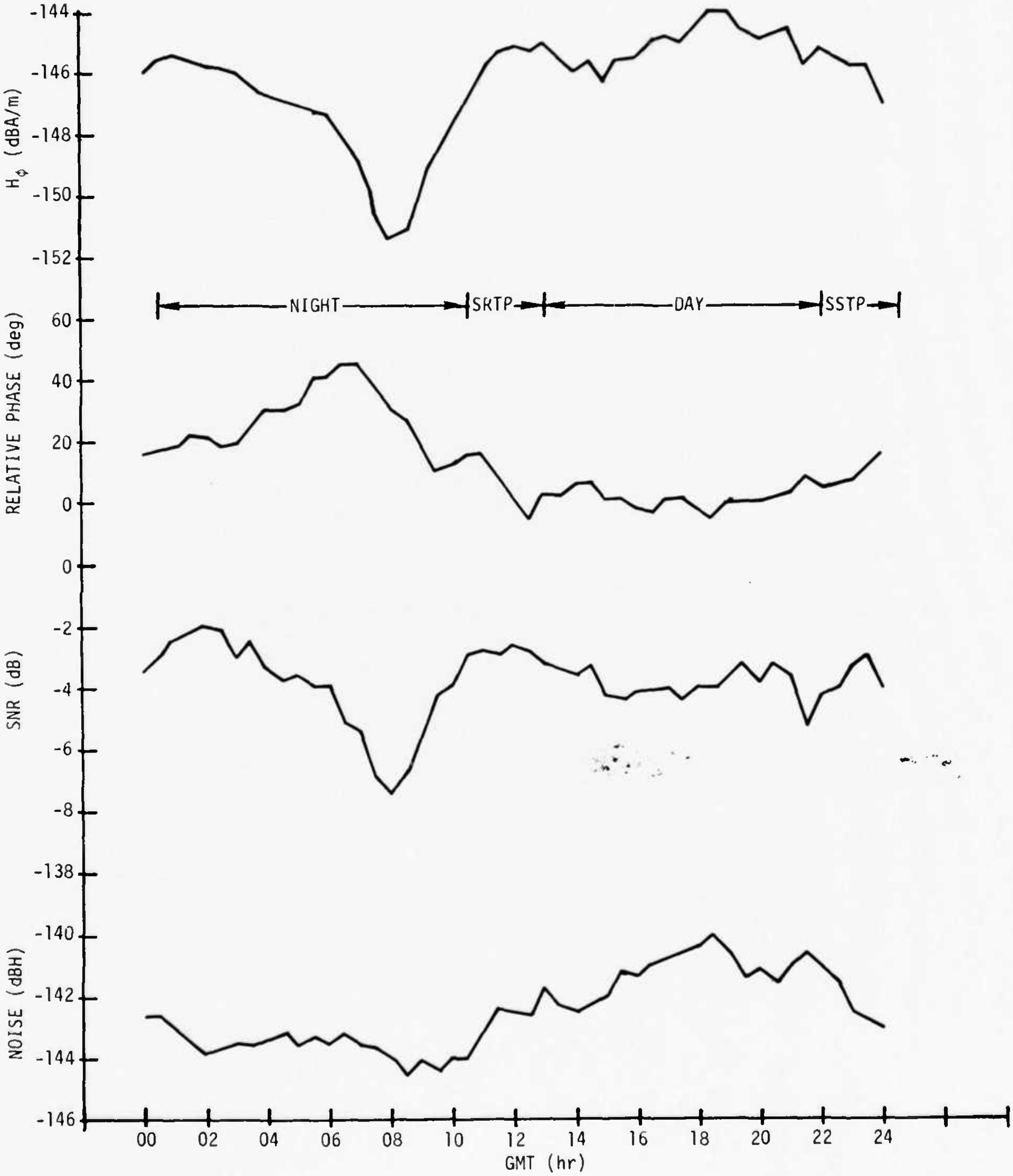


Figure B-17. Connecticut Data Versus GMT (ψ = 204 deg), 22 February 1977

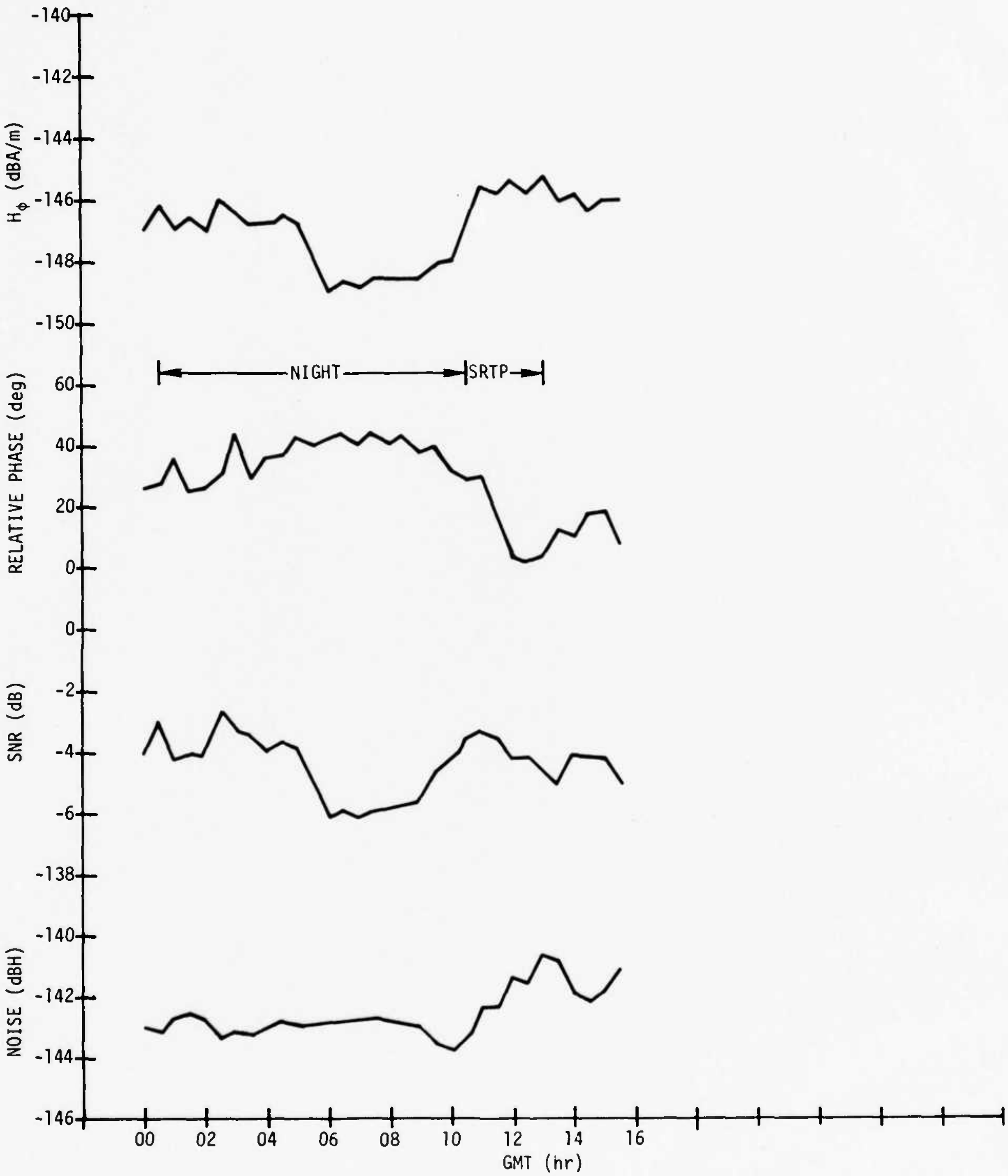


Figure B-18. Connecticut Data Versus GMT (ψ = 204 deg), 23 February 1977

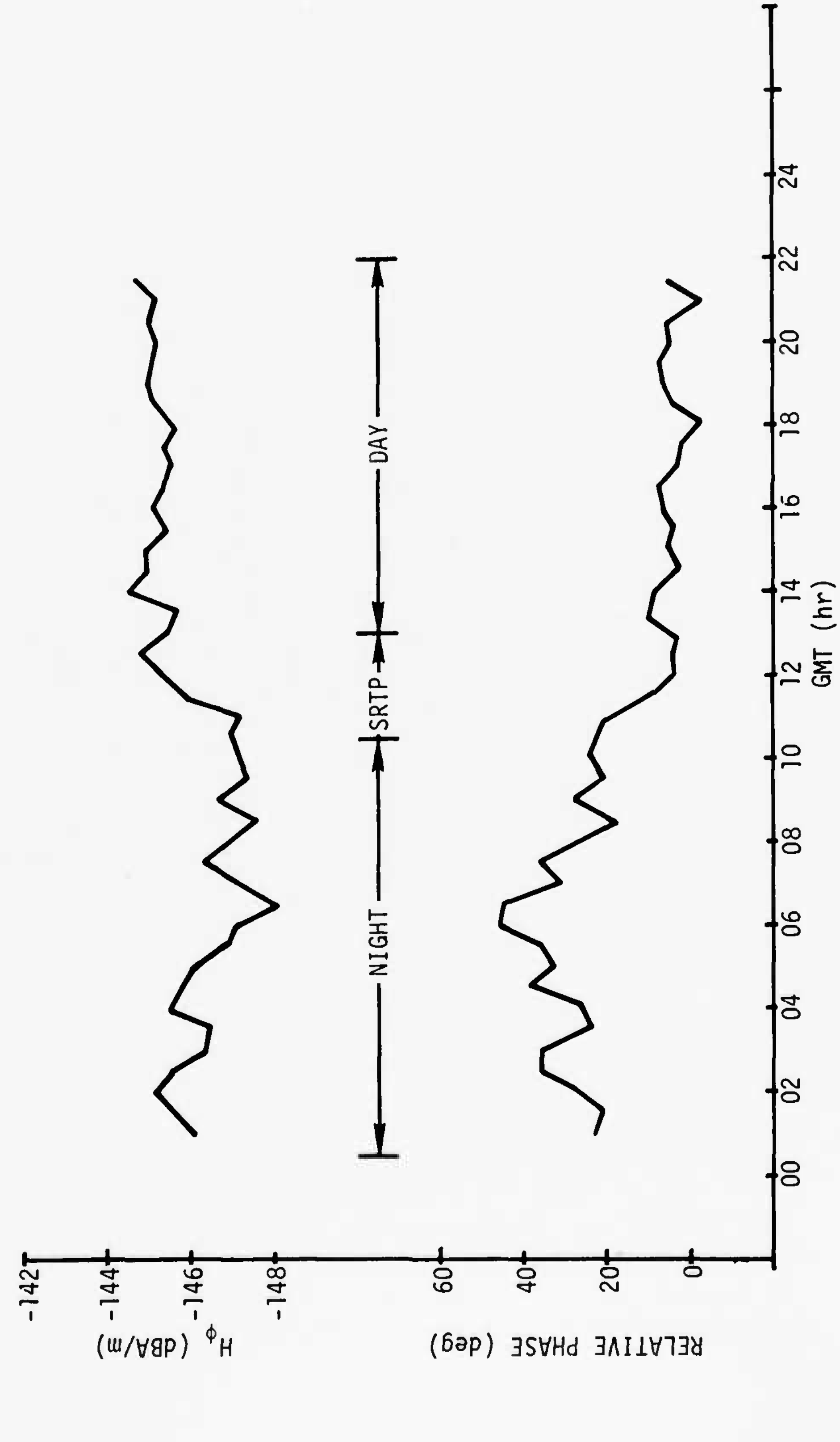


Figure B-19. Connecticut Data Versus GMT (ψ = 114 deg), 24 February 1977

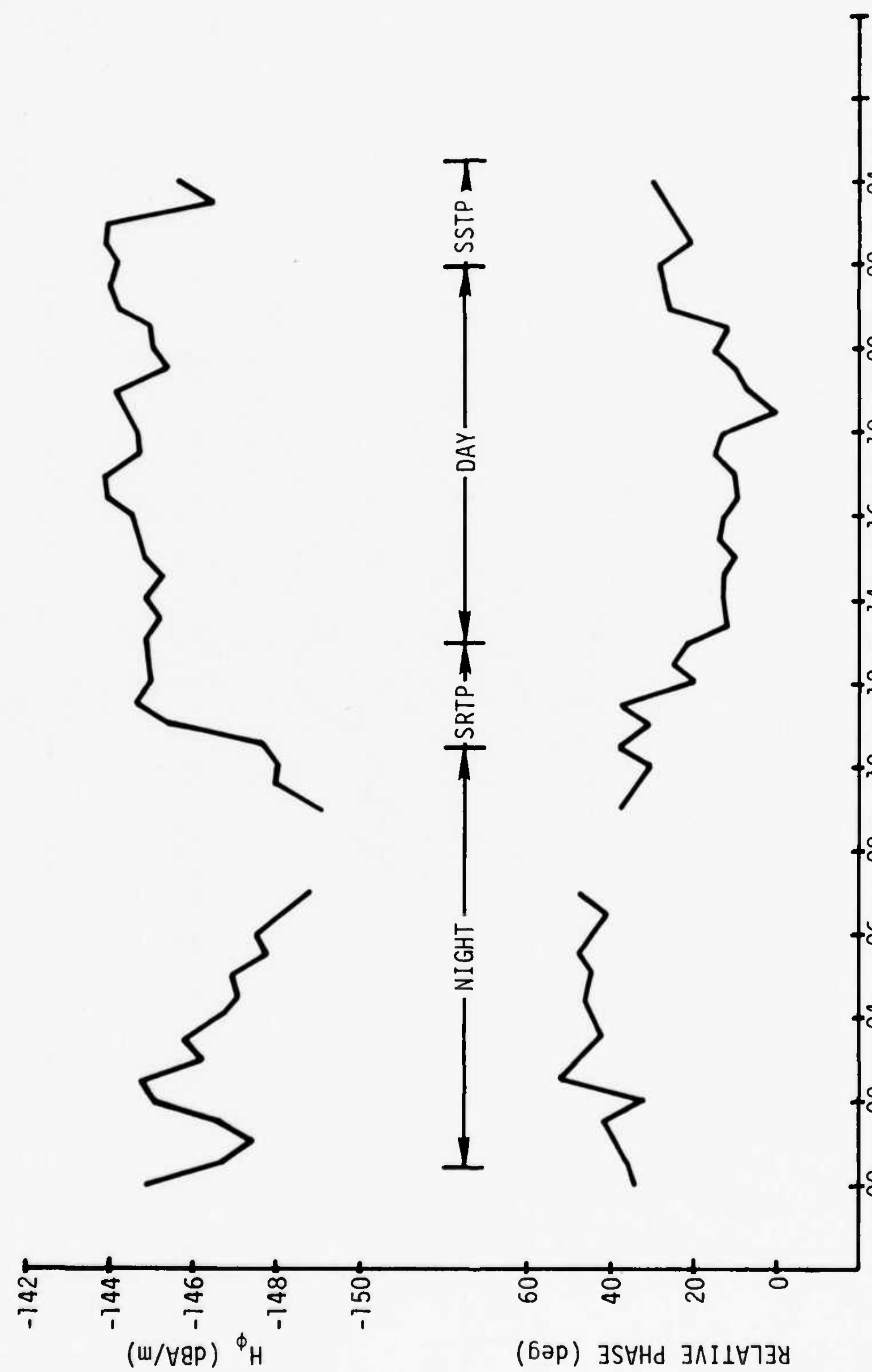


Figure B-20. Connecticut Data Versus GMT (ψ = 201 deg), 25 February 1977

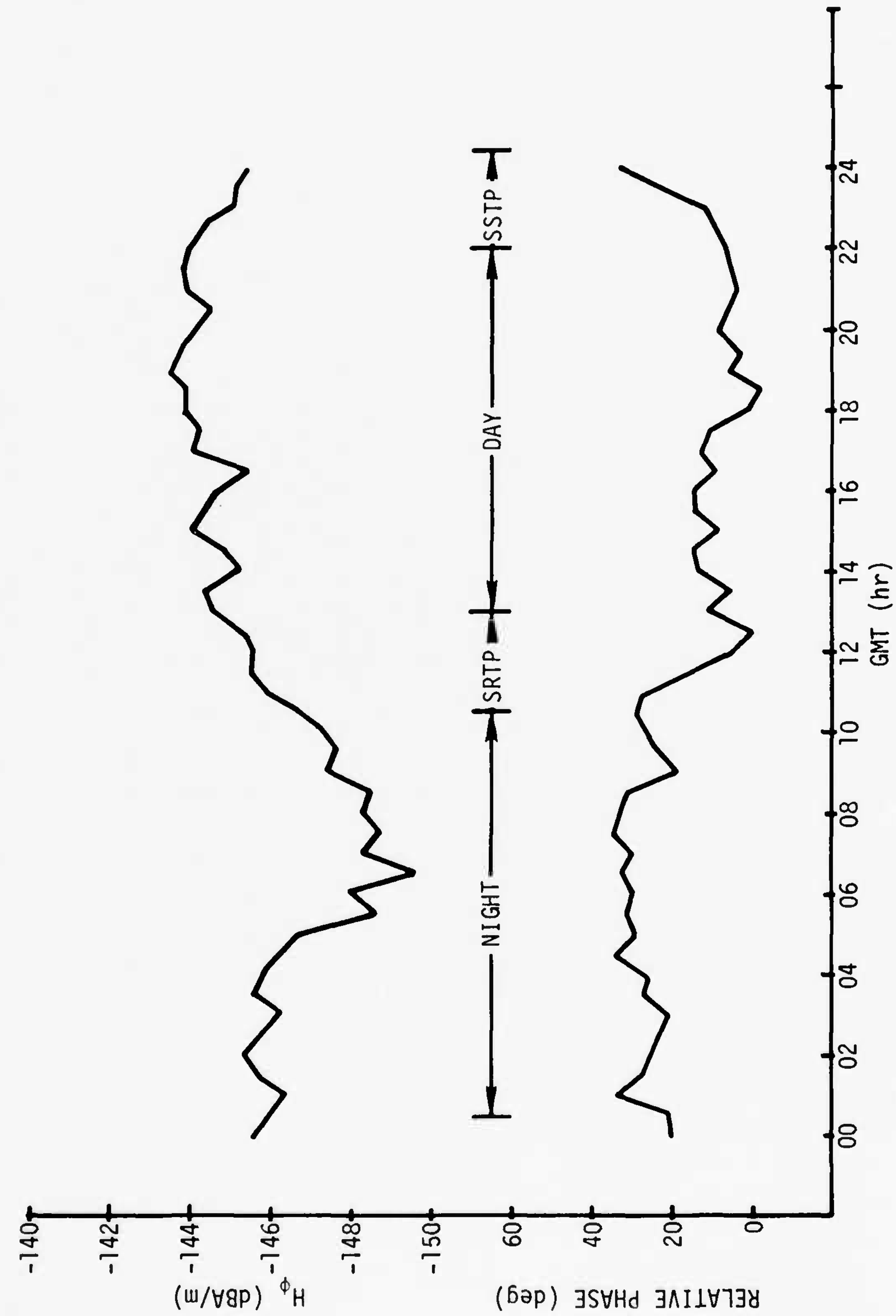


Figure B-21. Connecticut Data Versus GMT (ψ = 201 deg), 26 February 1977

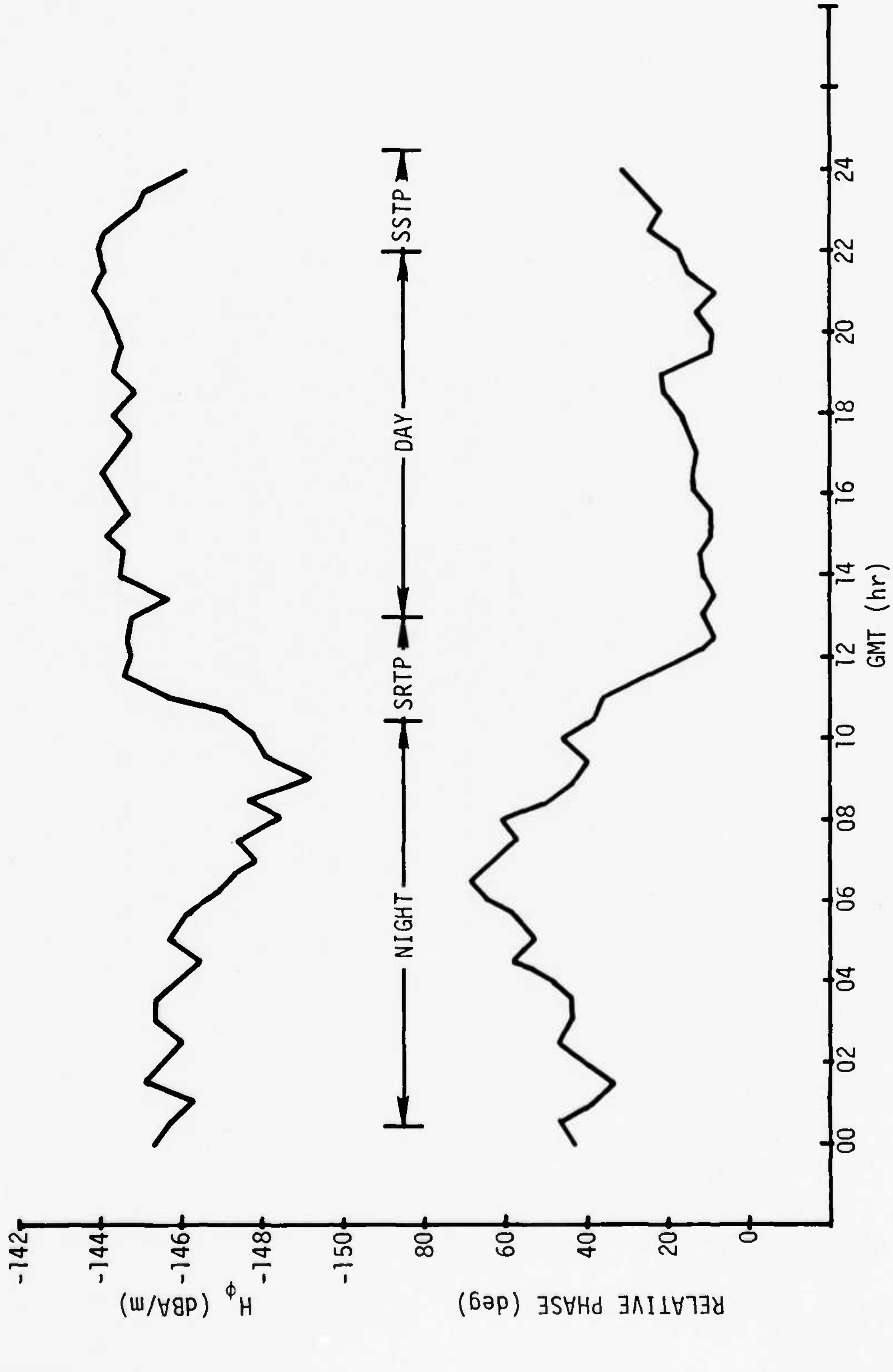


Figure B-22. Connecticut Data Versus GMT (ψ = 201 deg), 27 February 1977

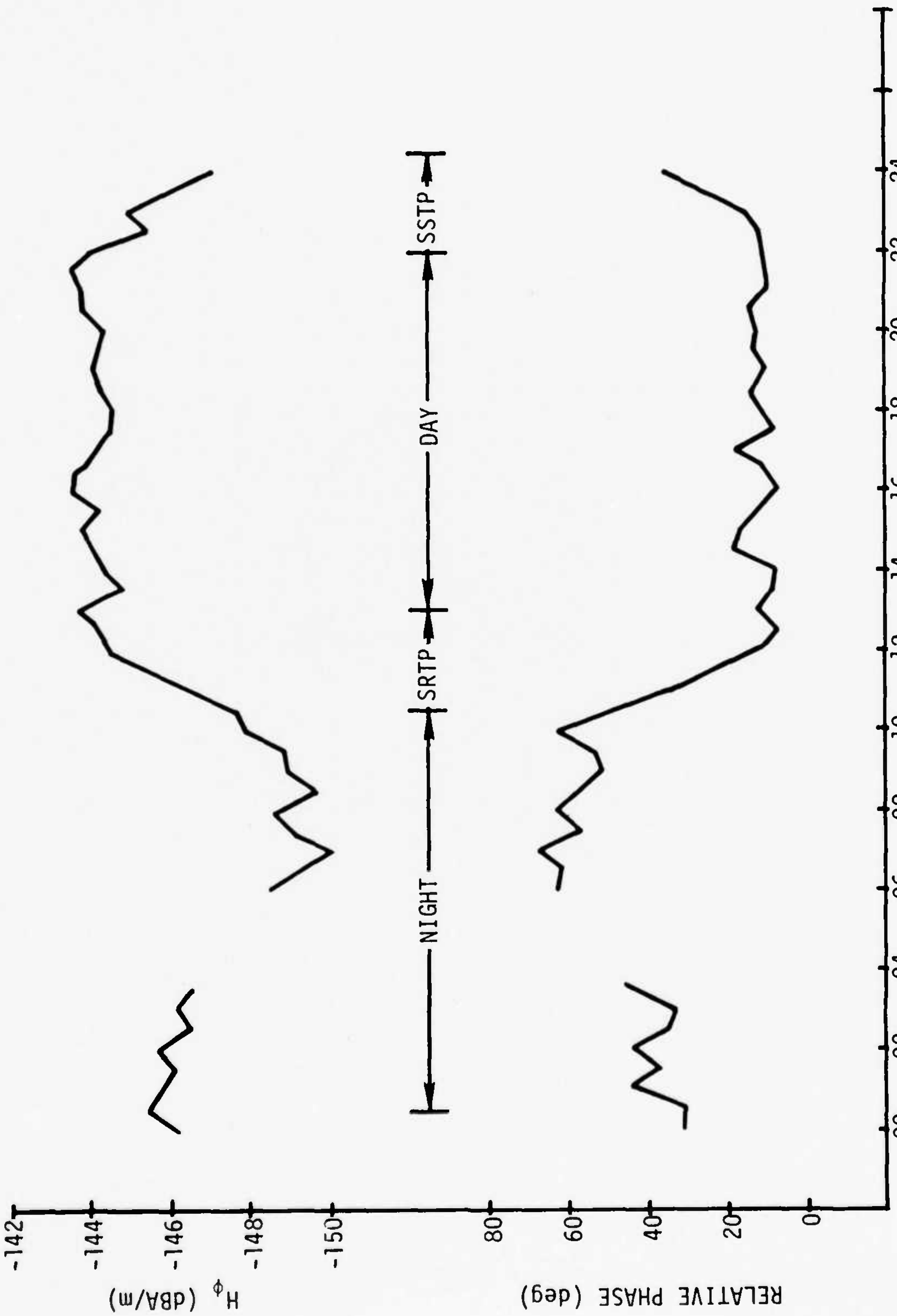


Figure B-23. Connecticut Data Versus GMT (ψ = 201 deg), 28 February 1977

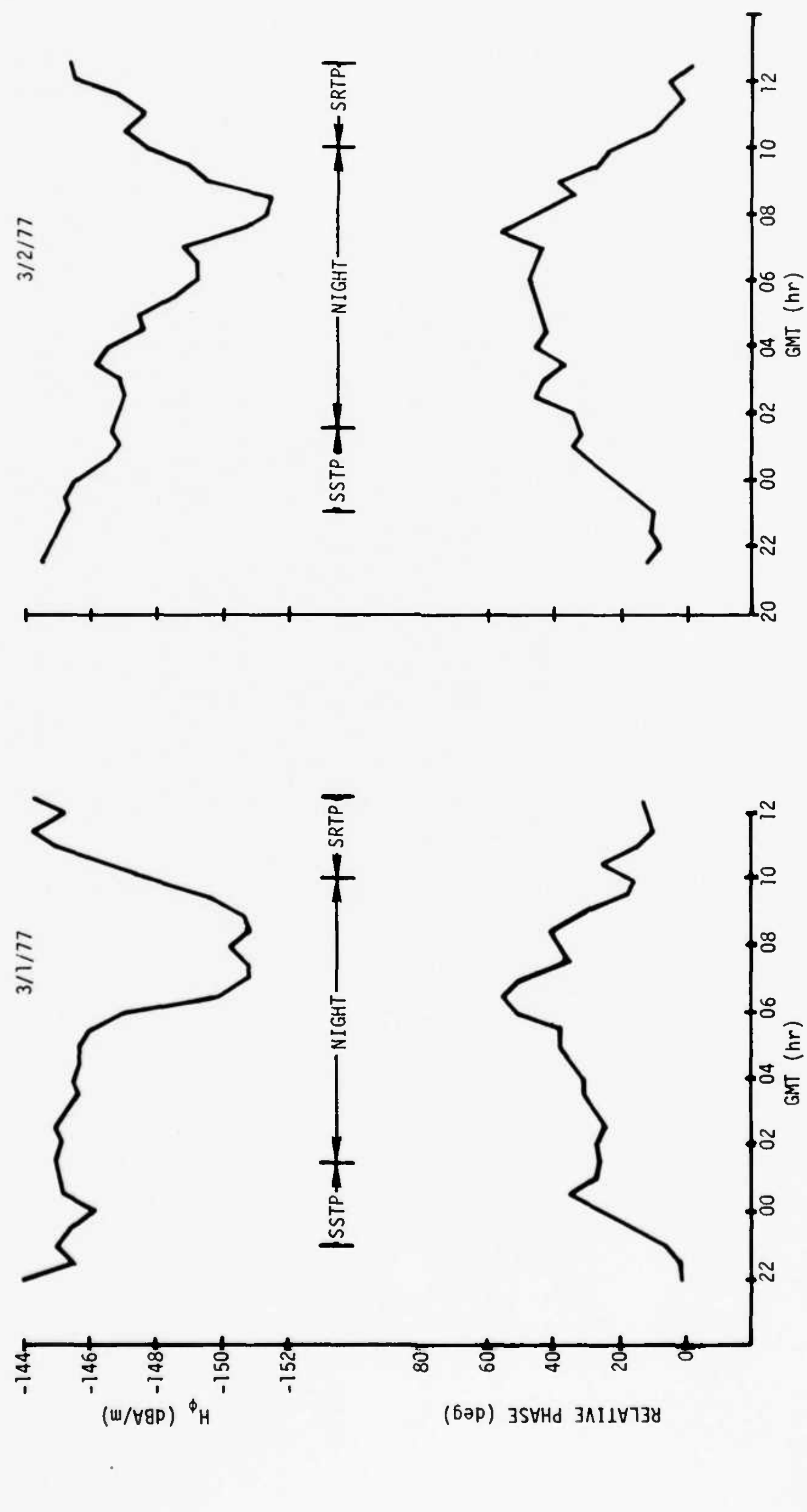


Figure B-24. Connecticut Data Versus GMT (ψ = 201 deg), 1 and 2 March 1977

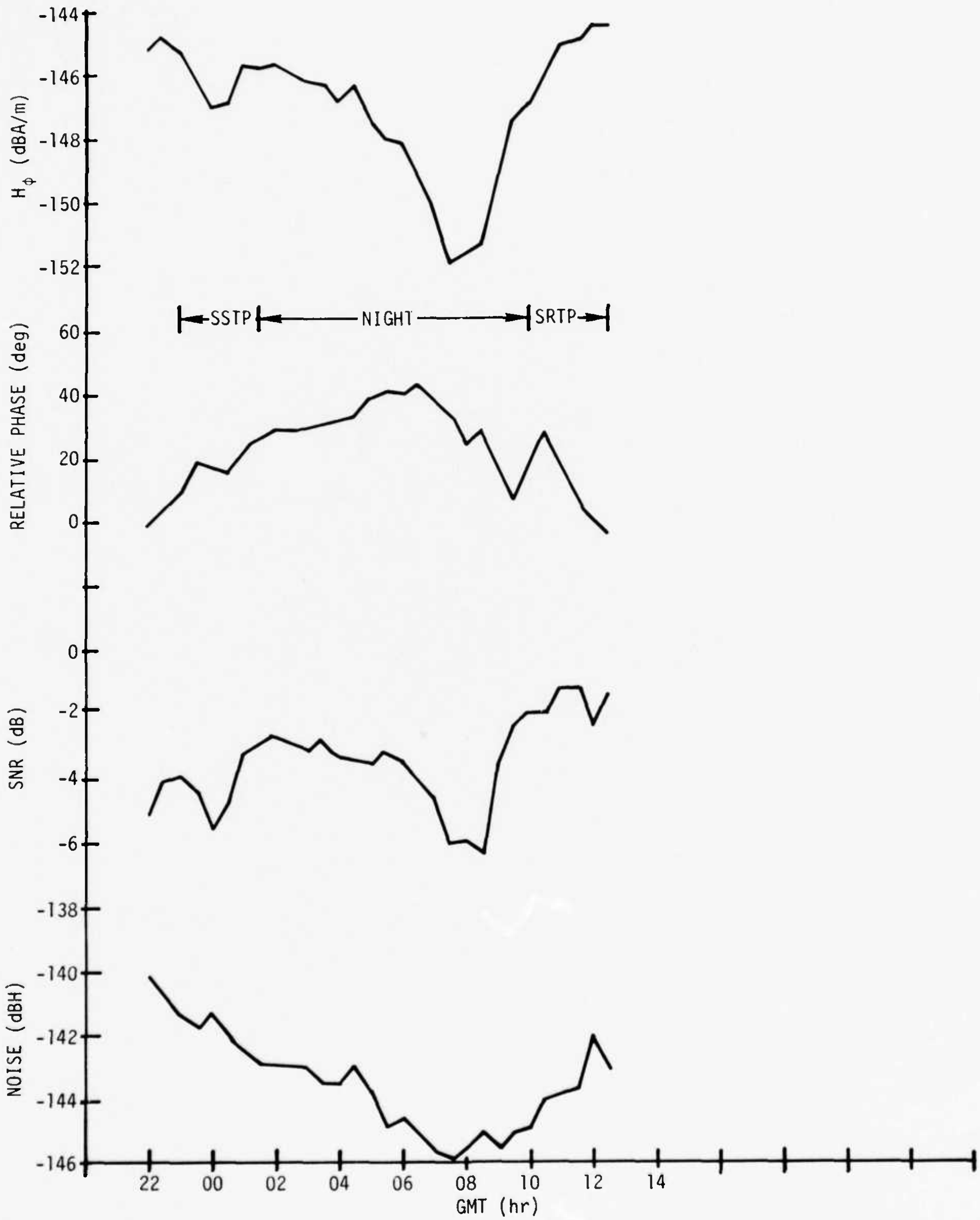


Figure B-25. Connecticut Data Versus GMT
(ψ = 201 deg), 3 March 1977

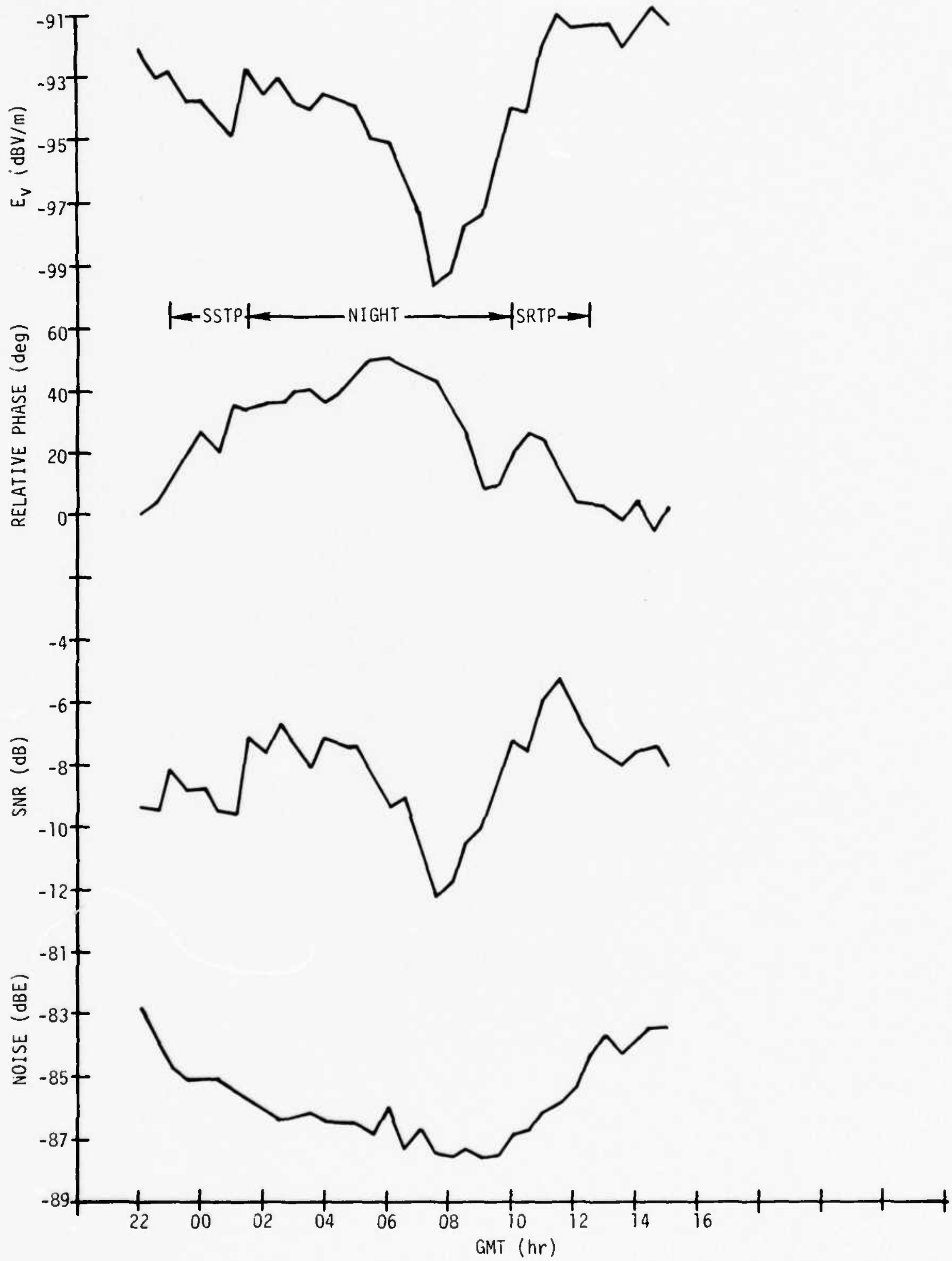


Figure B-26. Connecticut Whip Data Versus GMT
(ψ = 201 deg), 3 March 1977

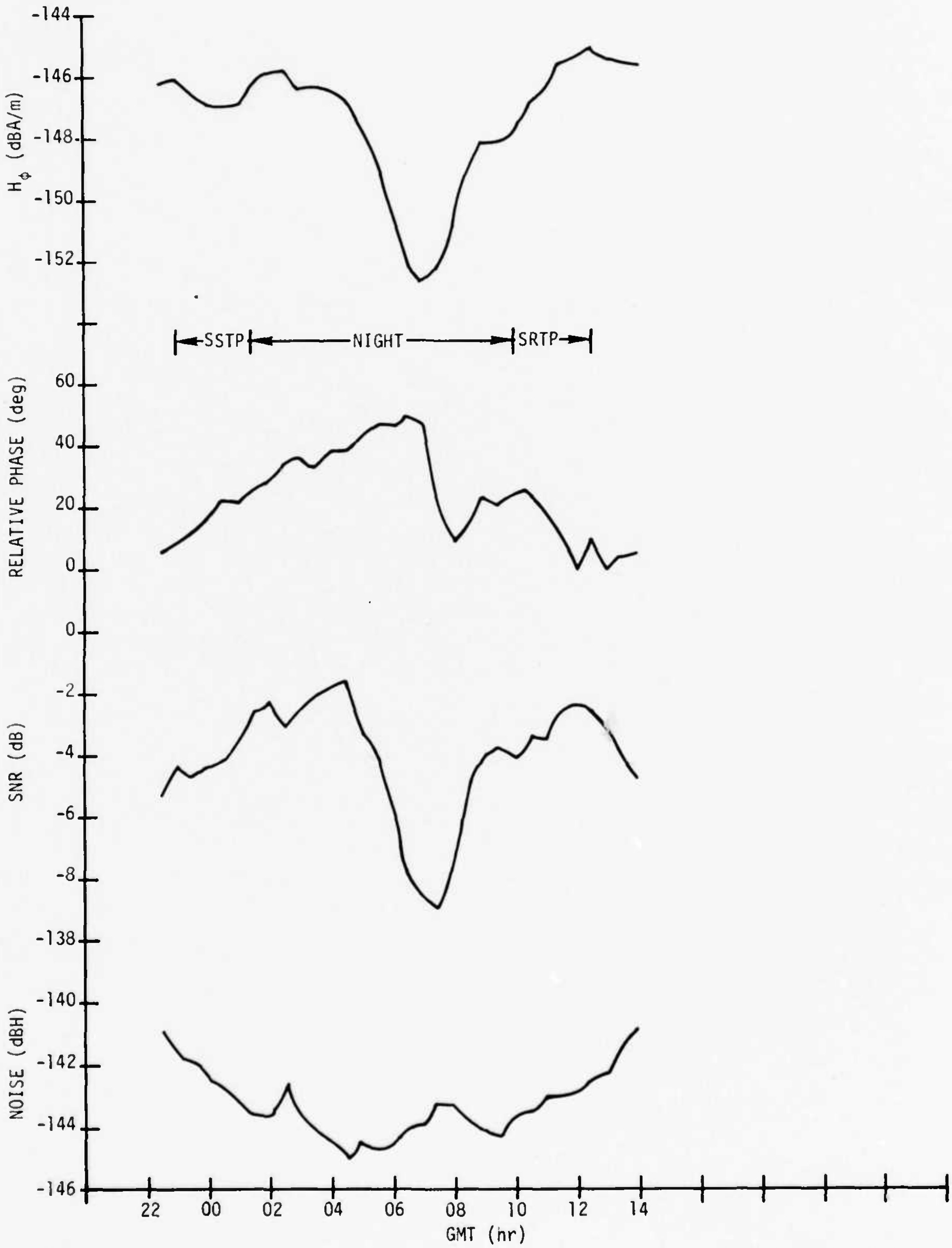


Figure B-27. Connecticut Data Versus GMT
(ψ = 201 deg), 4 March 1977

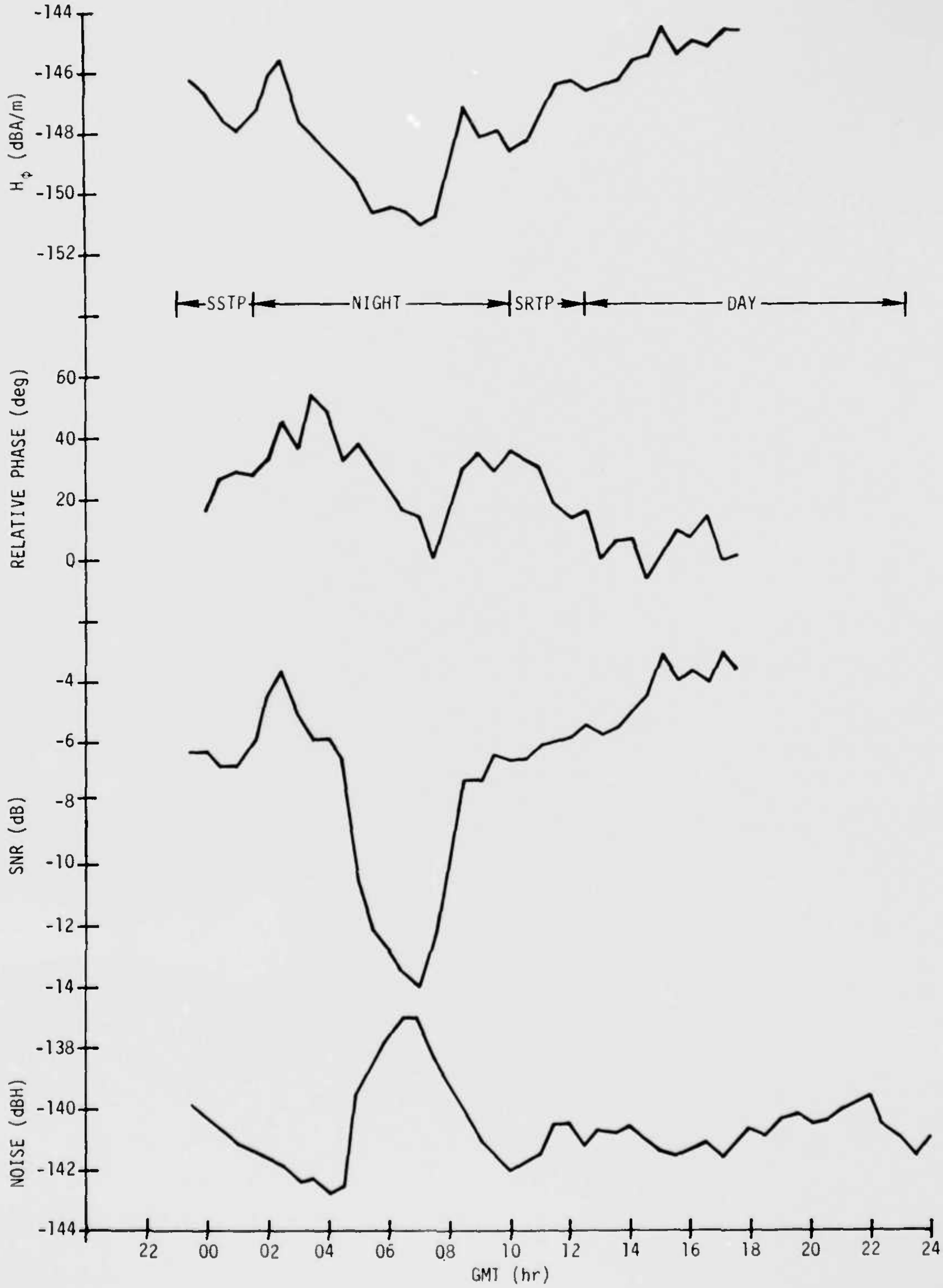


Figure B-28. Connecticut Data Versus GMT (ψ = 201 deg), 5 March 1977

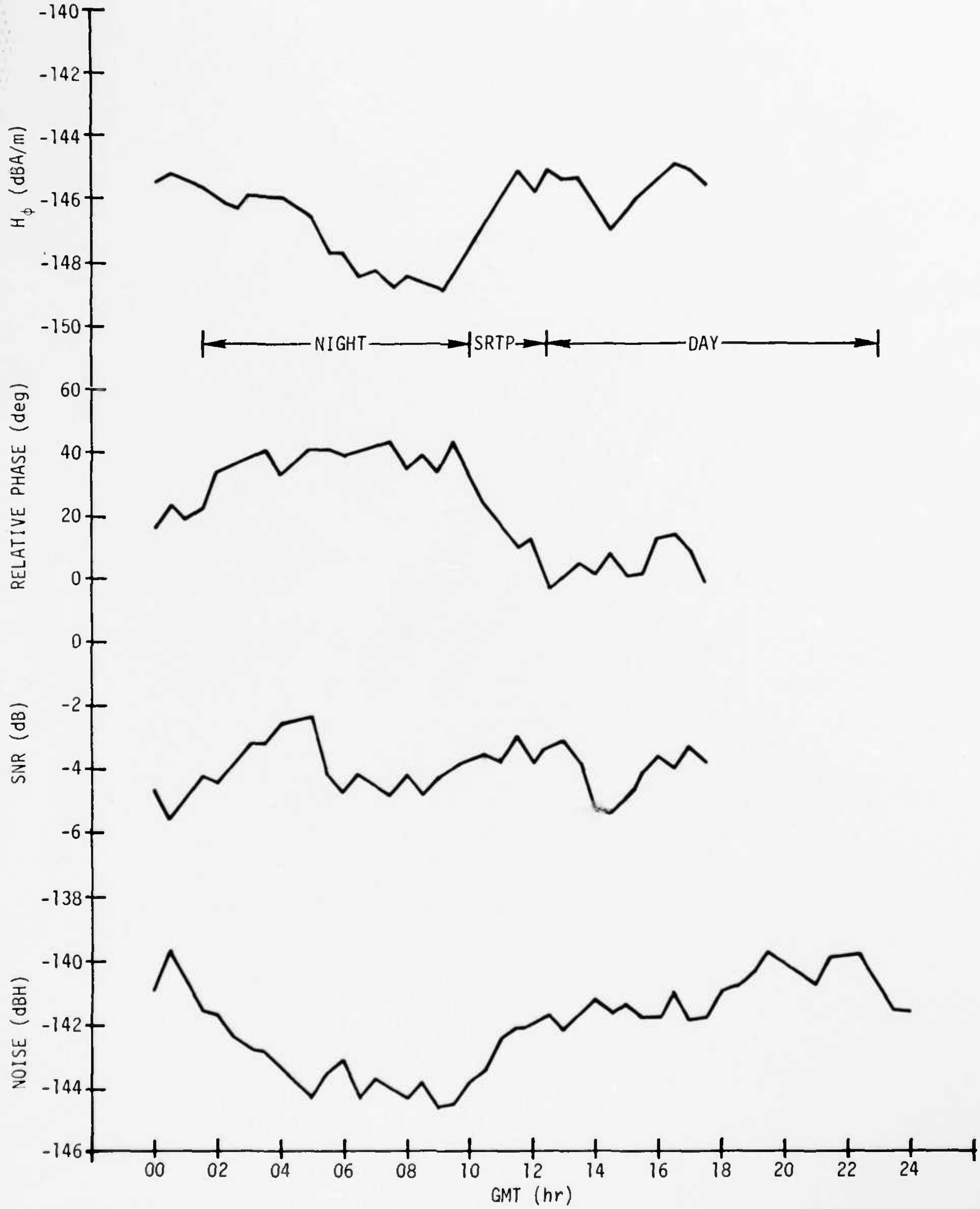


Figure B-29. Connecticut Data Versus GMT
(ψ = 111 deg), 6 March 1977

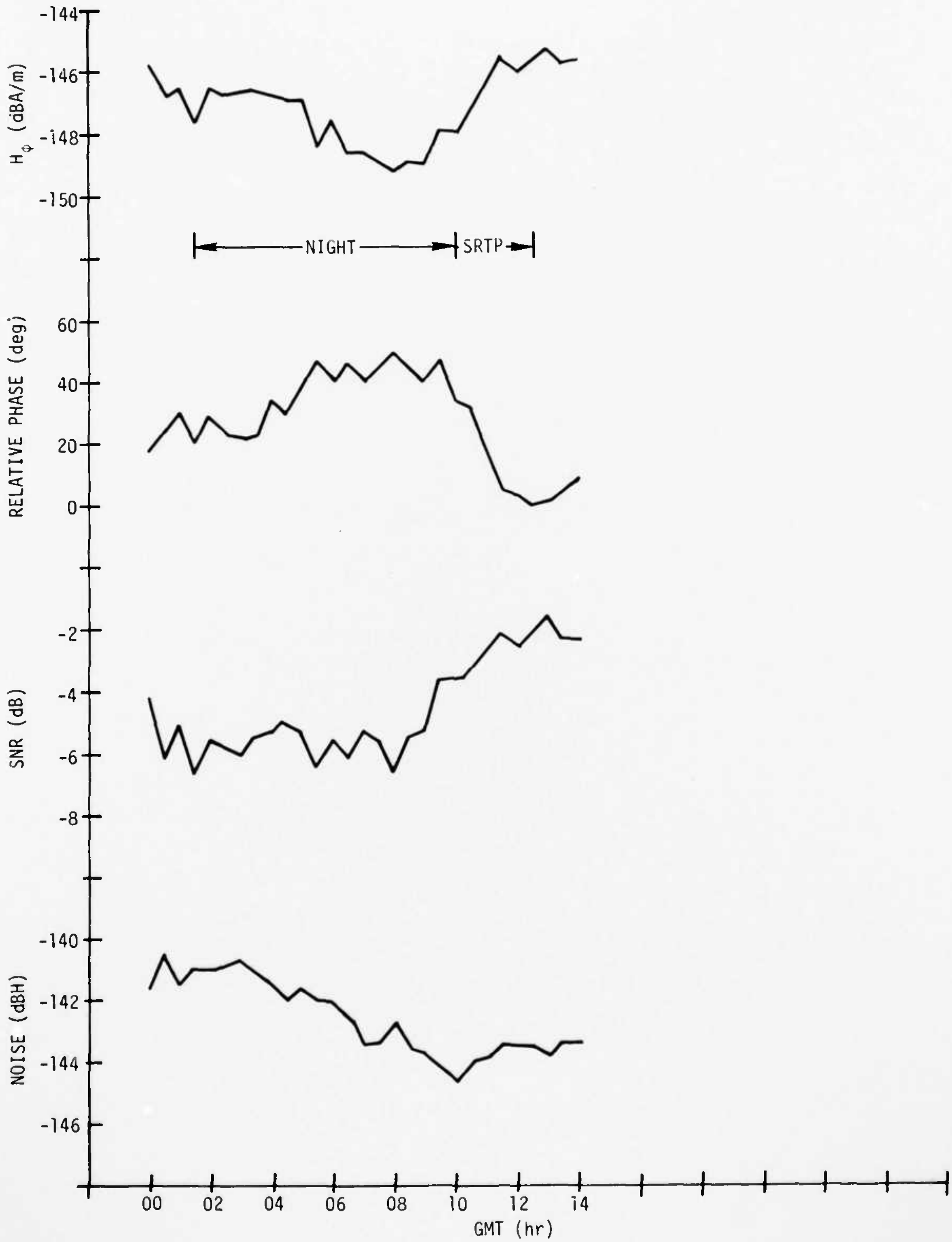


Figure B-30. Connecticut Data Versus GMT
(ψ = 111 deg), 7 March 1977

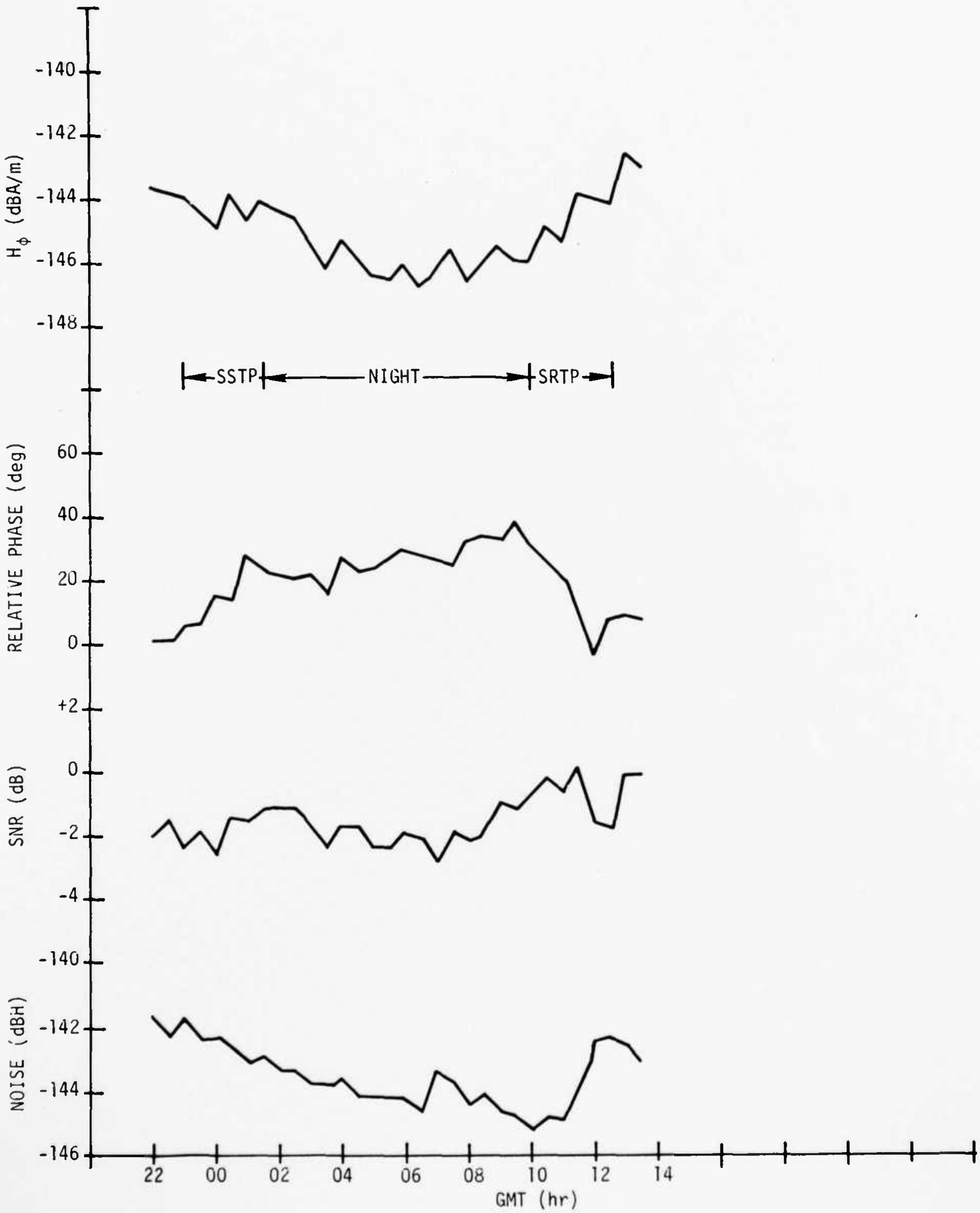


Figure B-31. Connecticut Data Versus GMT (ψ = 291 deg), 8 March 1977

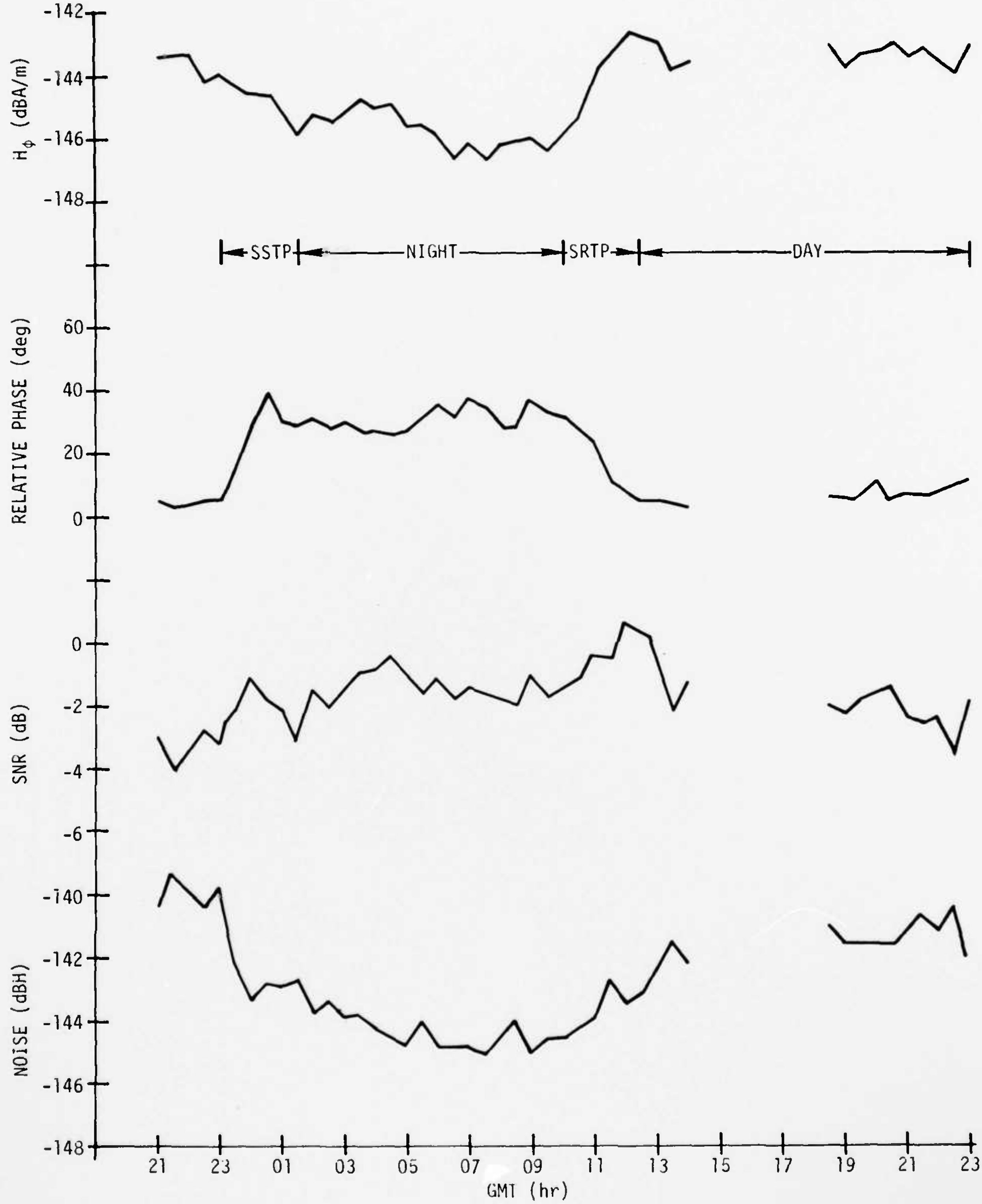


Figure B-32. Connecticut Data Versus GMT (ψ = 291 deg), 9 March 1977

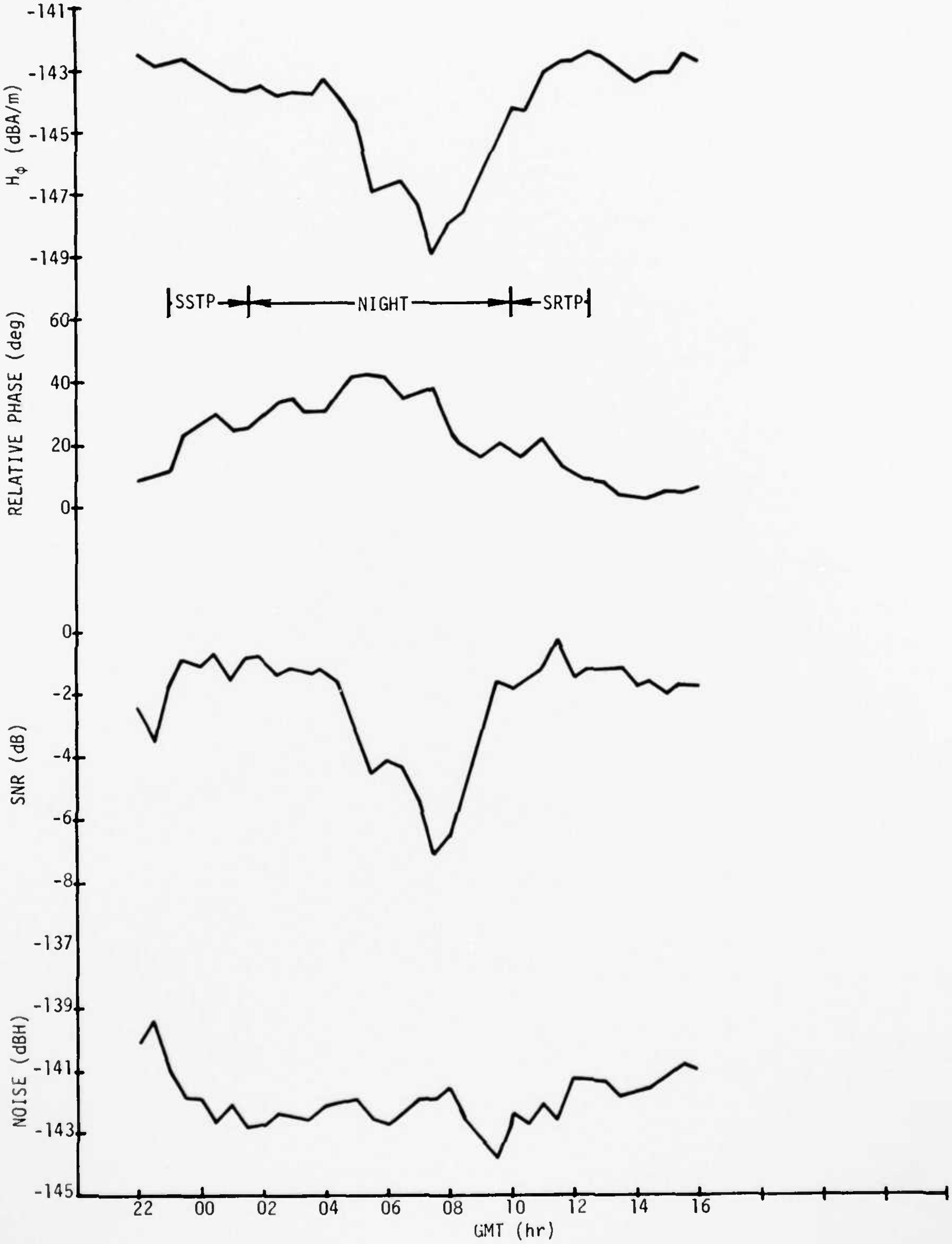


Figure B-33. Connecticut Data Versus GMT
(ψ = 291 deg), 10 March 1977

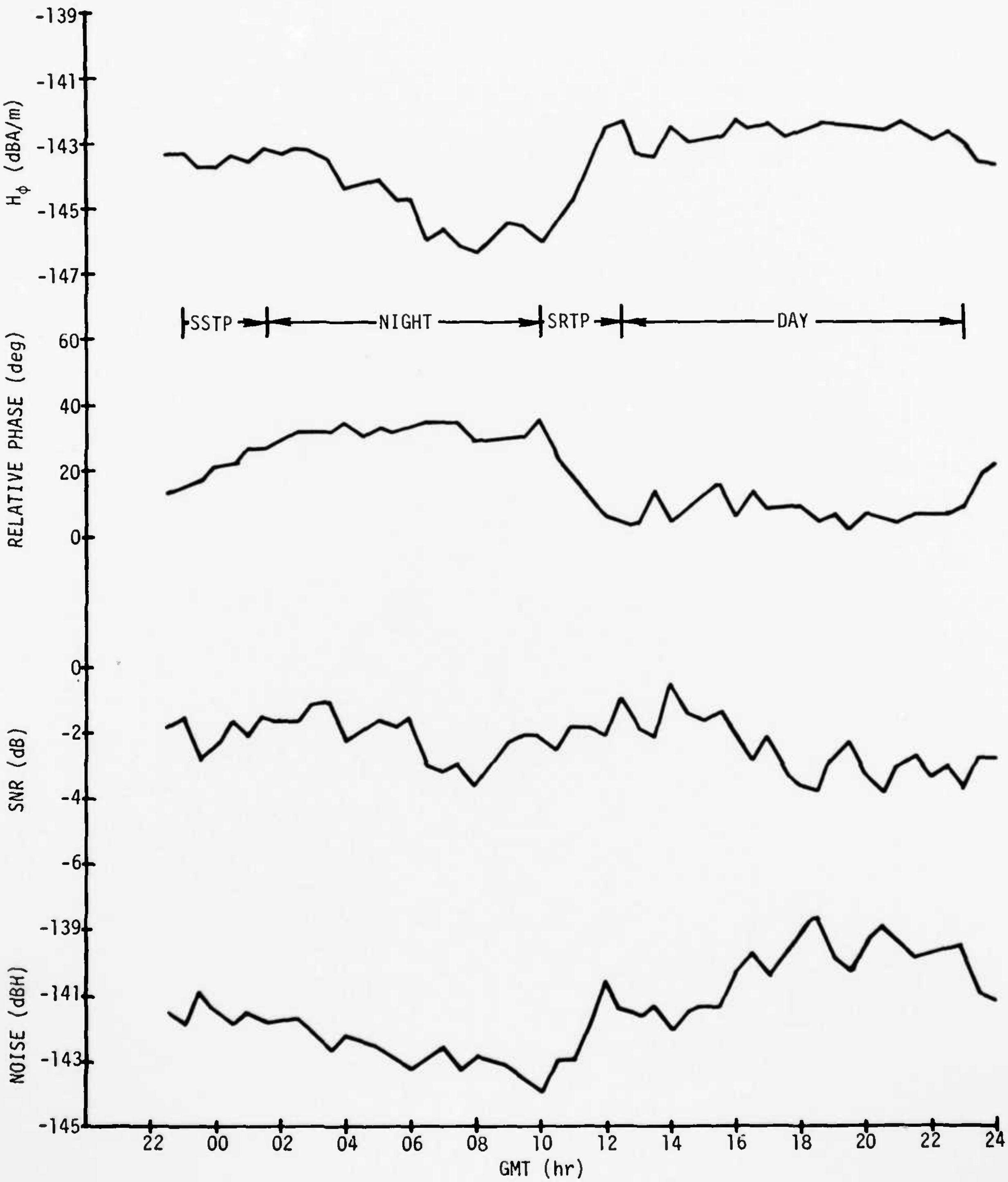


Figure B-34. Connecticut Data Versus GMT
(ψ = 291 deg), 11 March 1977

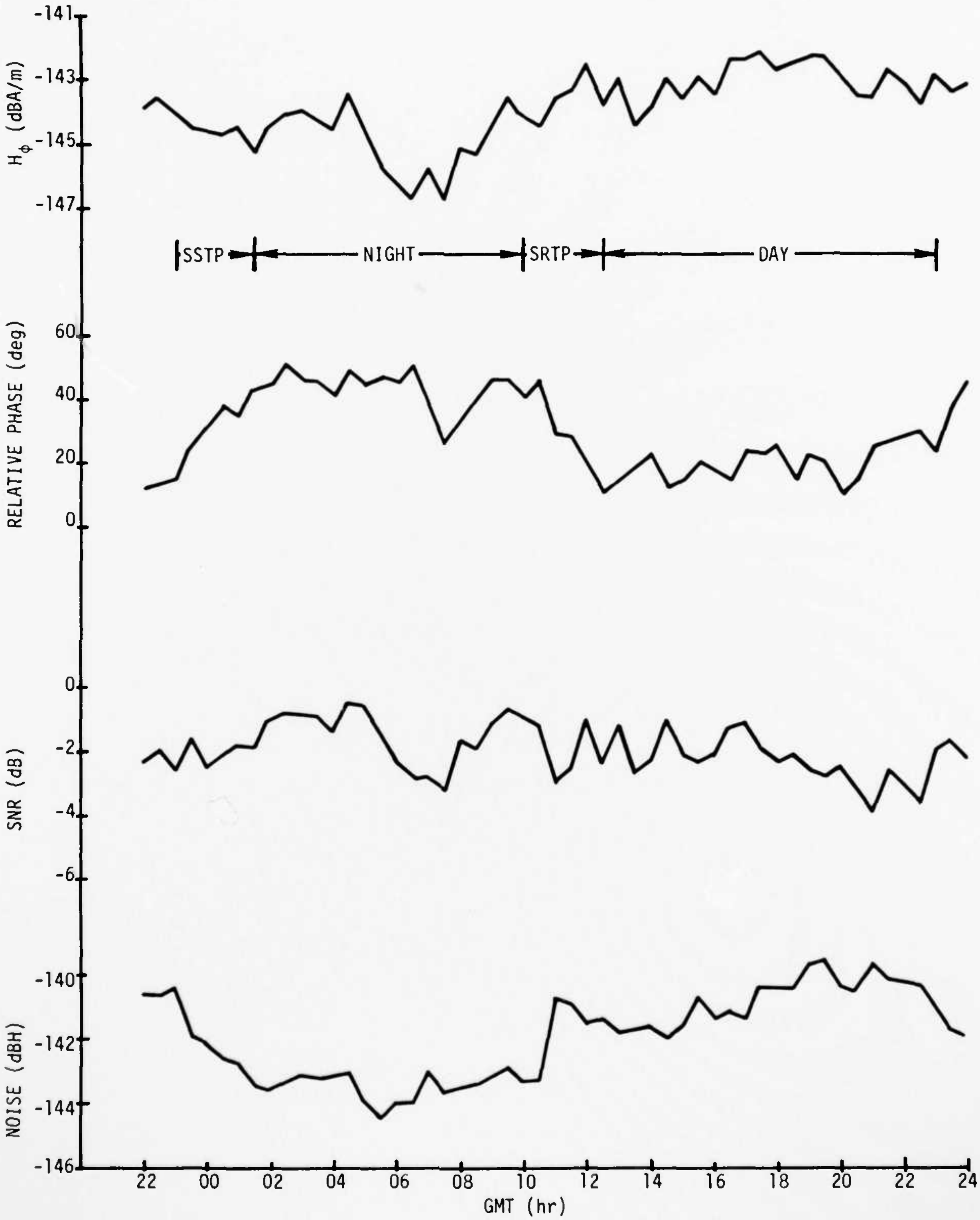


Figure B-35. Connecticut Data Versus GMT
(ψ = 291 deg), 12 March 1977

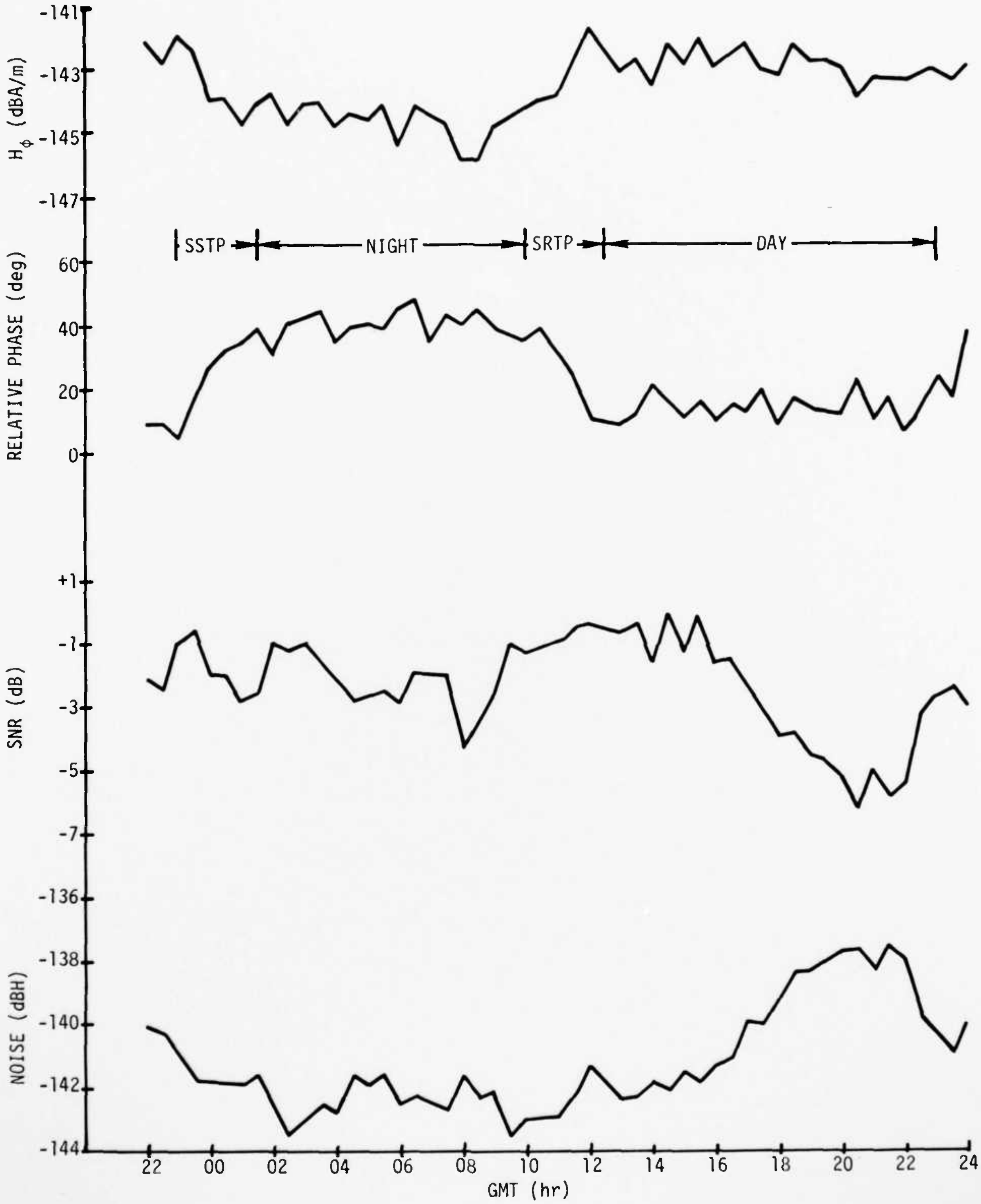


Figure B-36. Connecticut Data Versus GMT
(ψ = 291 deg), 13 March 1977

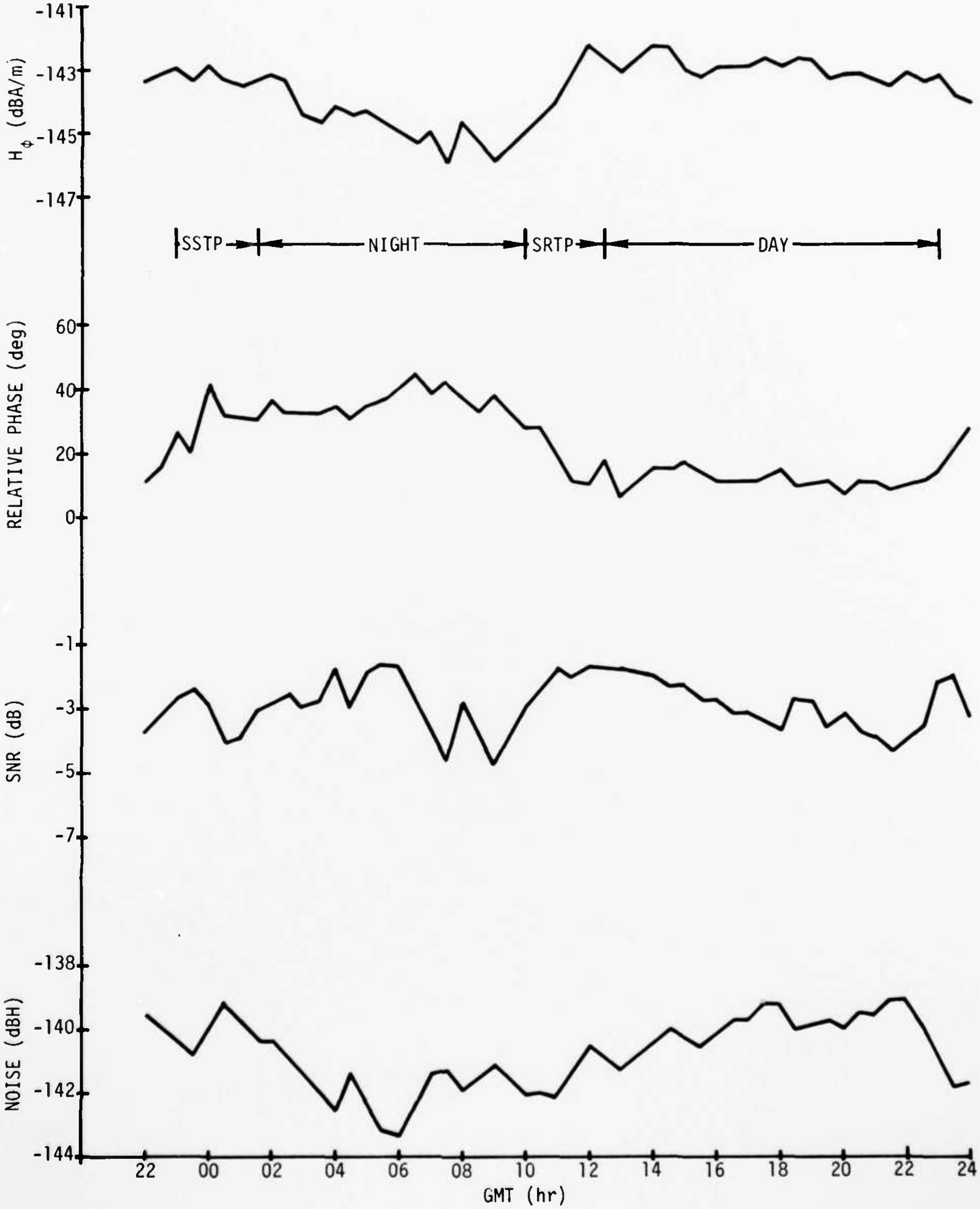


Figure B-37. Connecticut Data Versus GMT (ψ = 291 deg), 14 March 1977

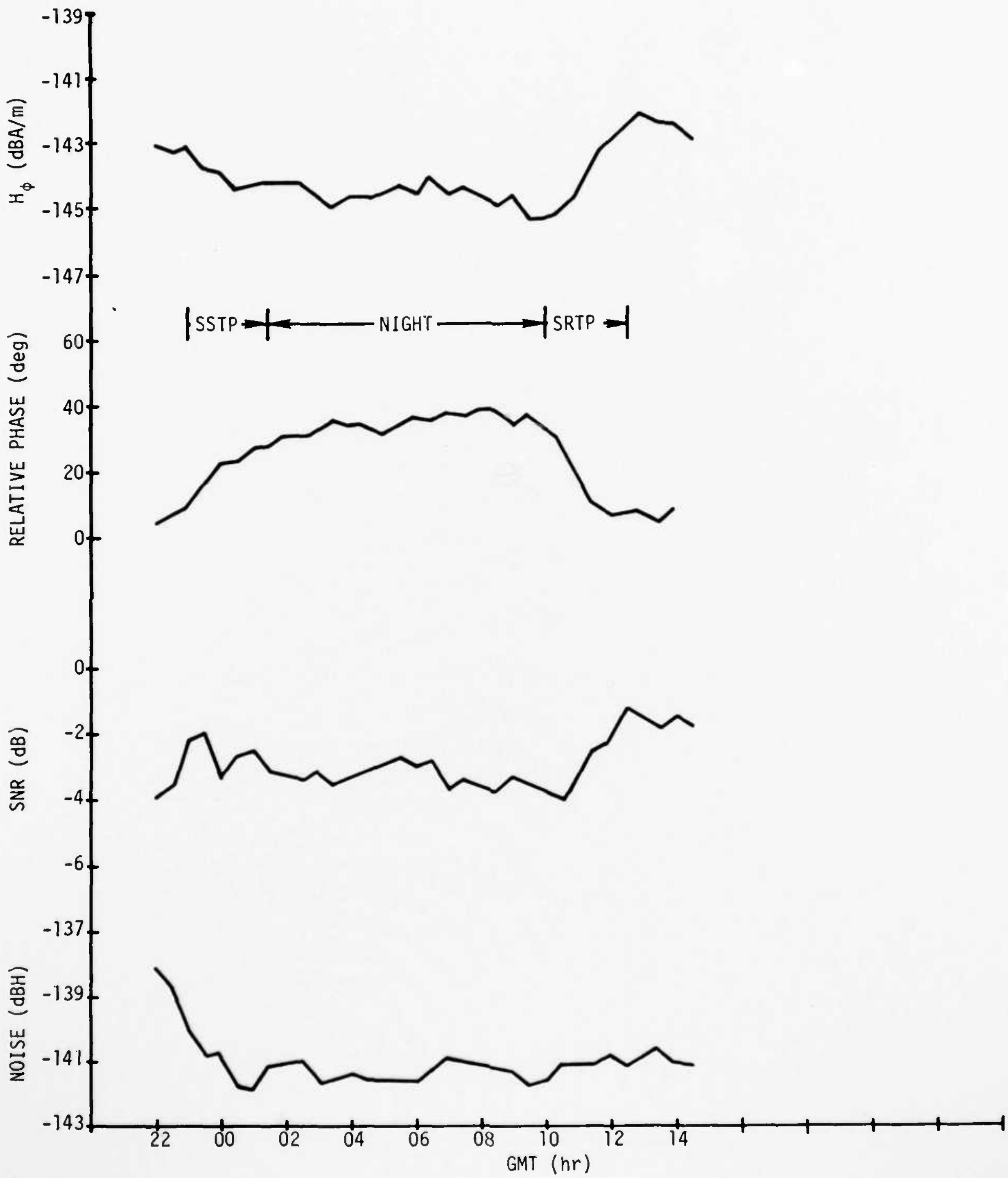


Figure B-38. Connecticut Data Versus GMT
(ψ = 291 deg), 15 March 1977

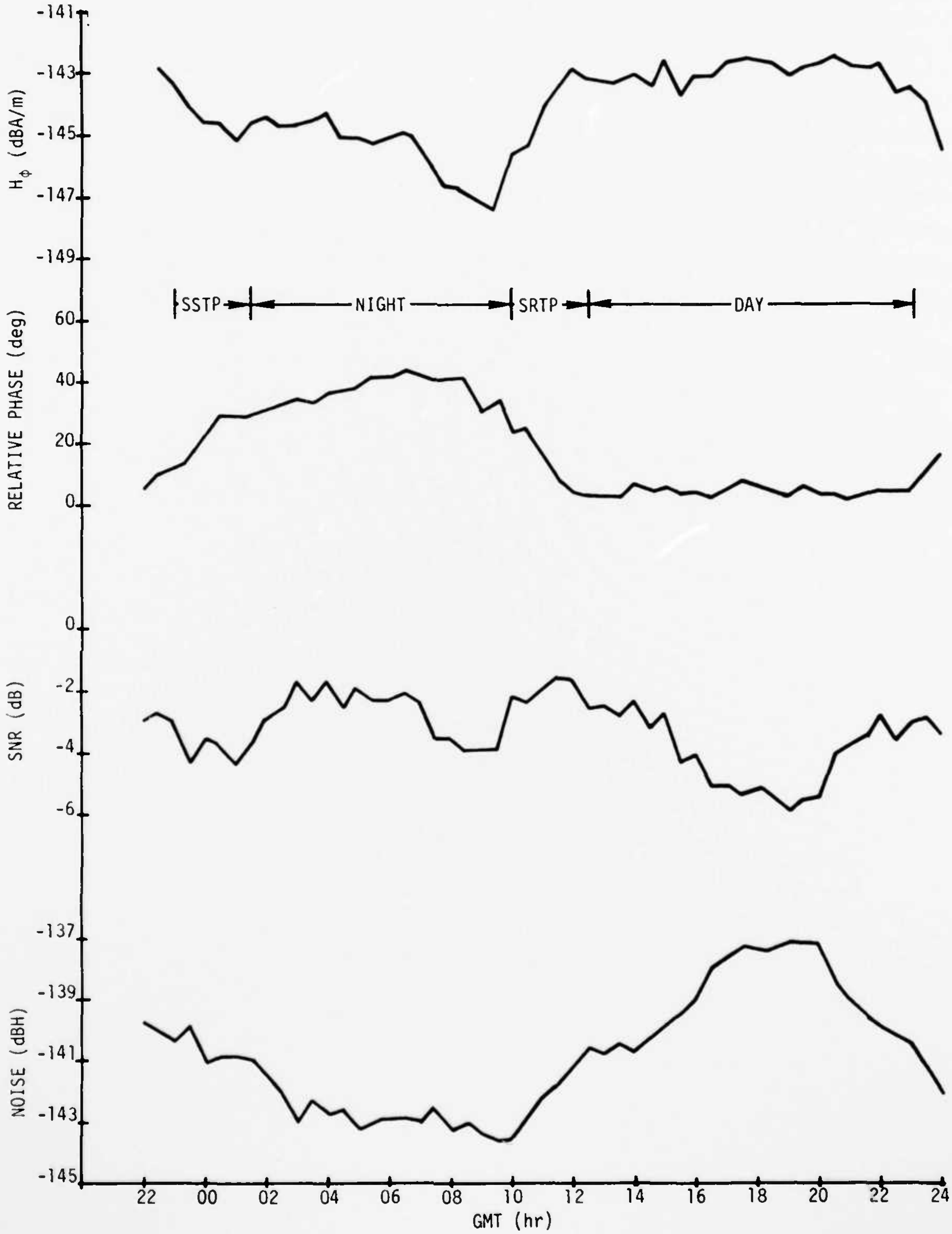


Figure B-39. Connecticut Data Versus GMT
(ψ = 291 deg), 16 March 1977

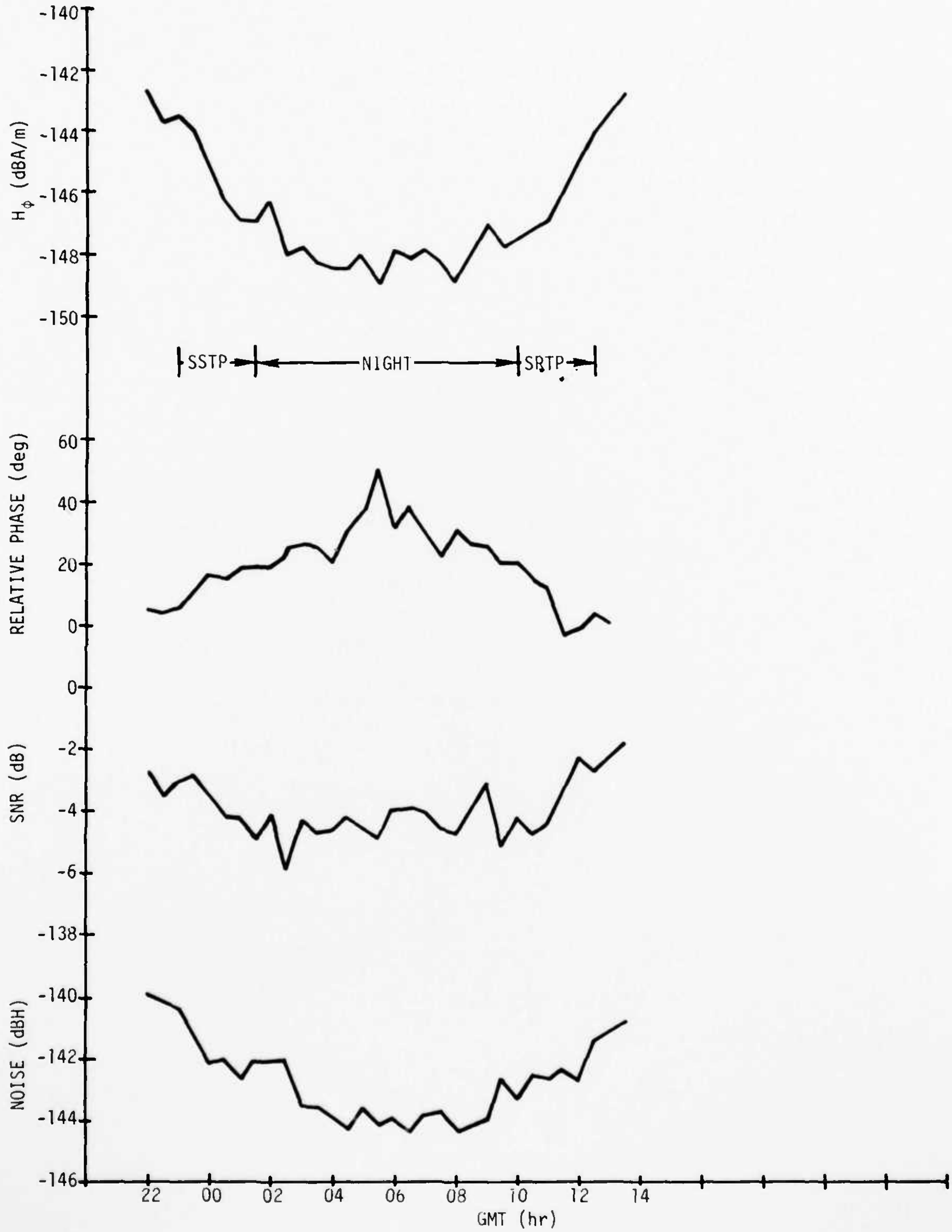


Figure B-40. Connecticut Data Versus GMT (ψ = 291 deg), 17 March 1977

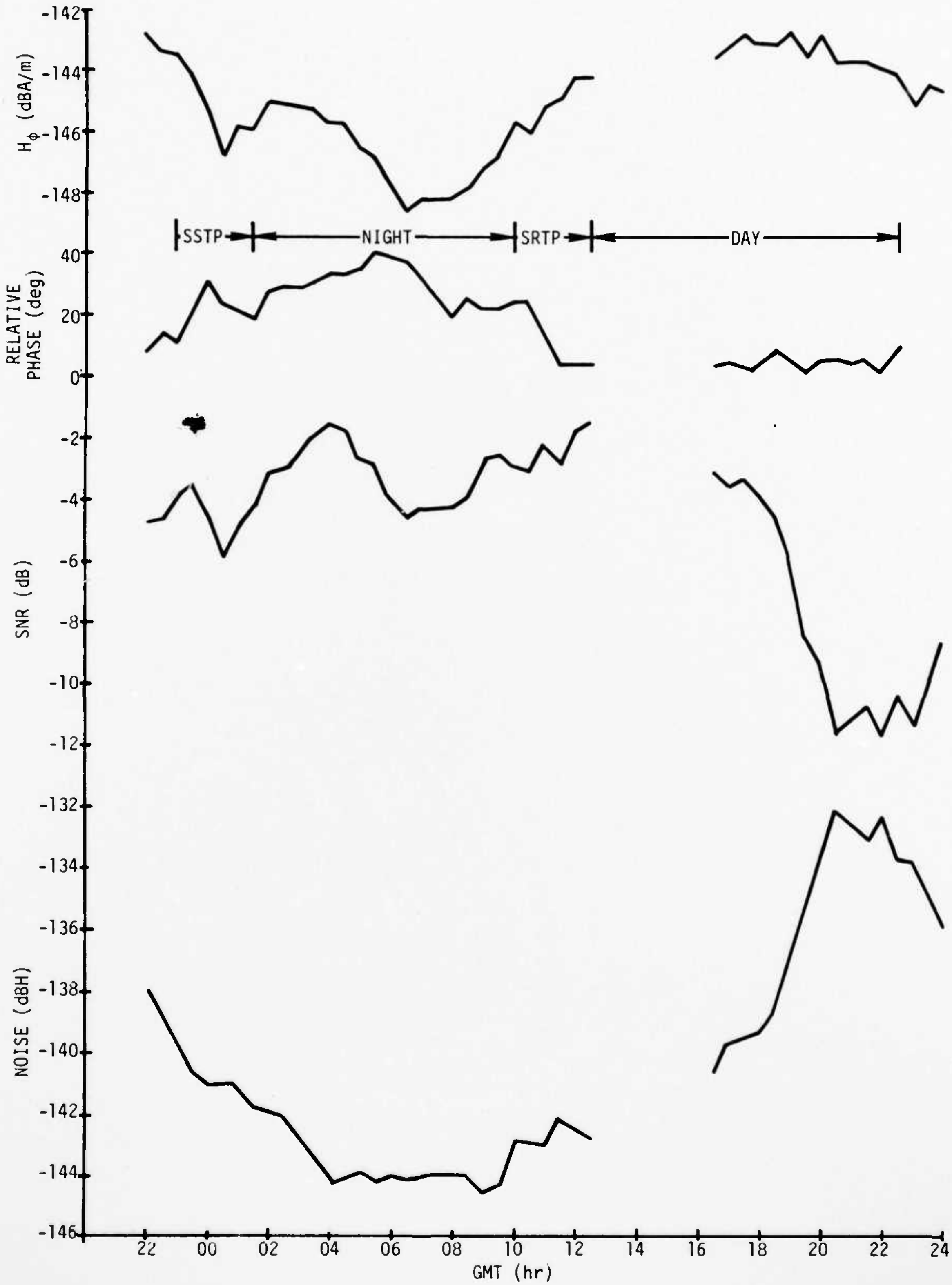


Figure B-41. Connecticut Data Versus GMT
(ψ = 291 deg), 18 March 1977

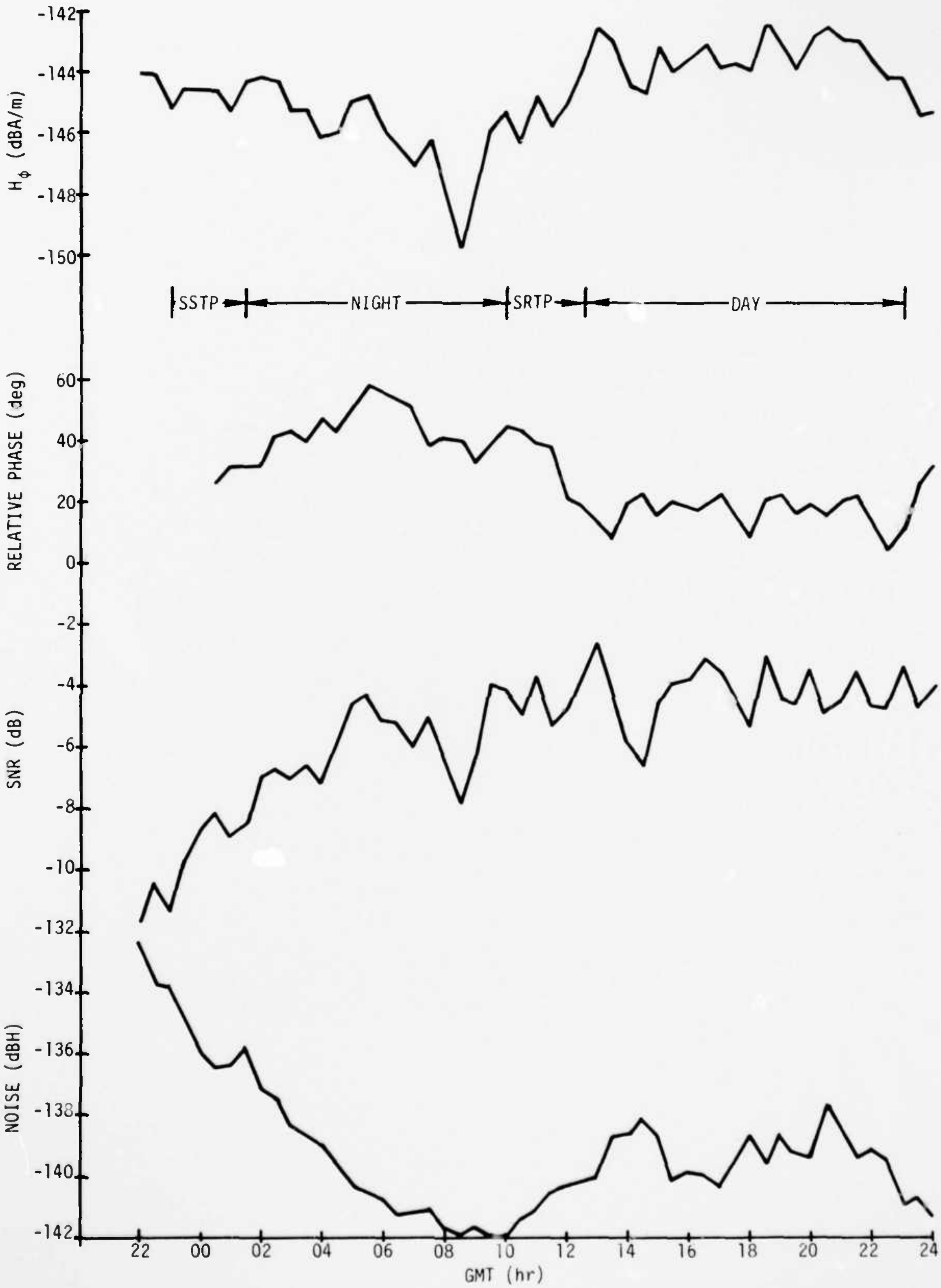
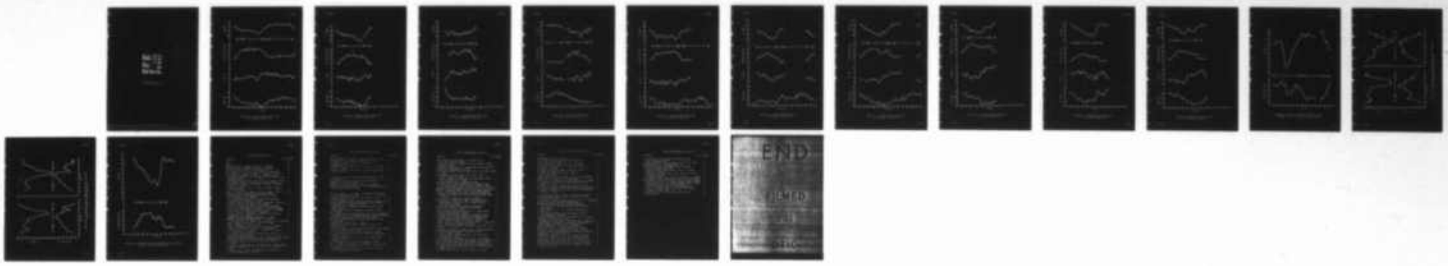
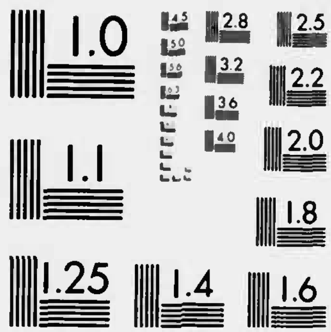


Figure B-42. Connecticut Data Versus GMT (ψ = 291 deg), 19 March 1977

AD-A128 178 ELF (EXTREMELY LOW FREQUENCY) PVS (PROPAGATION VALIDATION SYSTEM) FIELD S..(U) NAVAL UNDERWATER SYSTEMS CENTER NEW LONDON CT NEW LONDON LAB.. 2/2

UNCLASSIFIED P R BANNISTER 03 FEB 83 NUSC-TR-6769 F/G 20/14 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

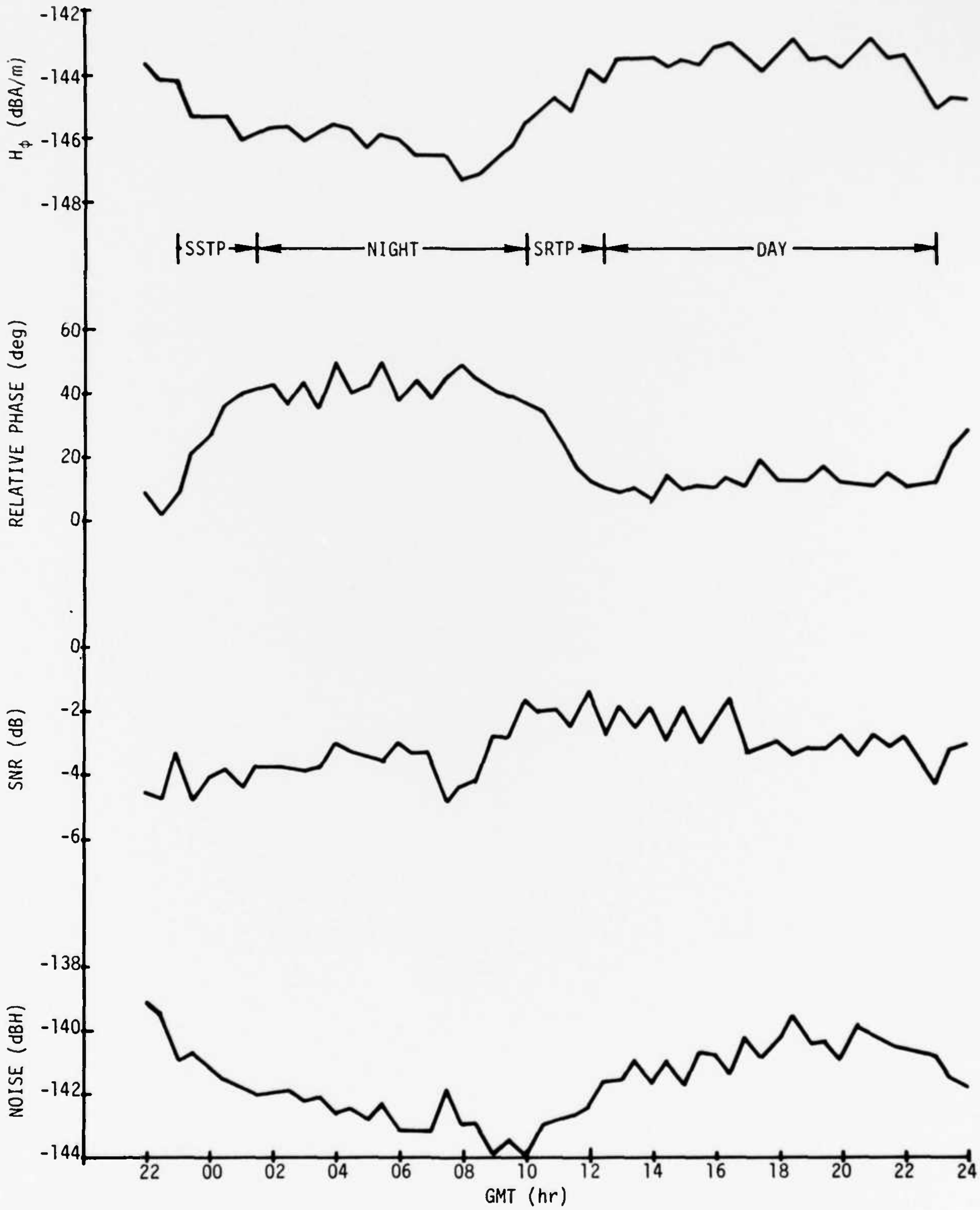


Figure B-43. Connecticut Data Versus GMT
(ψ = 291 deg), 20 March 1977

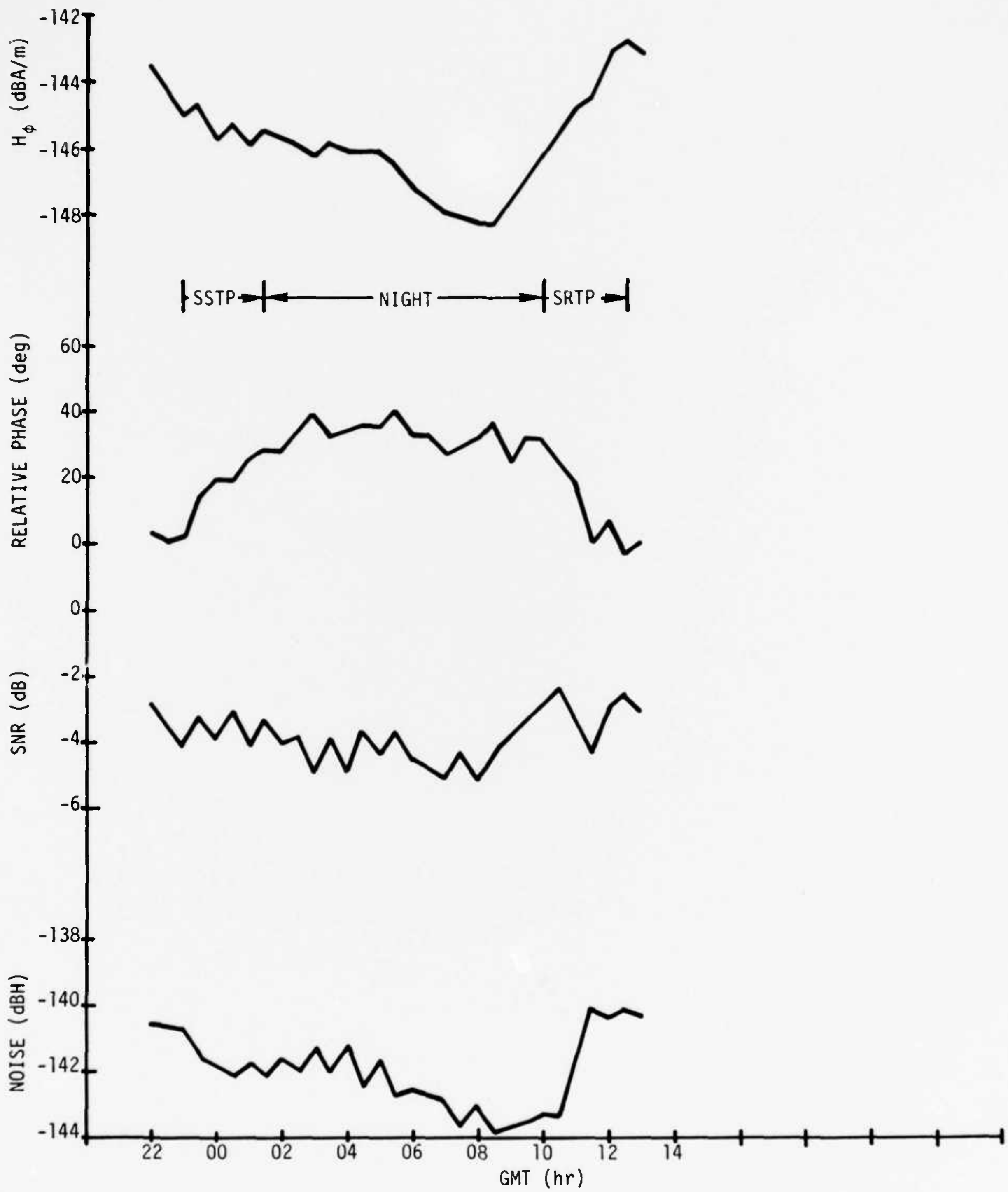


Figure B-44. Connecticut Data Versus GMT
(ψ = 291 deg), 21 March 1977

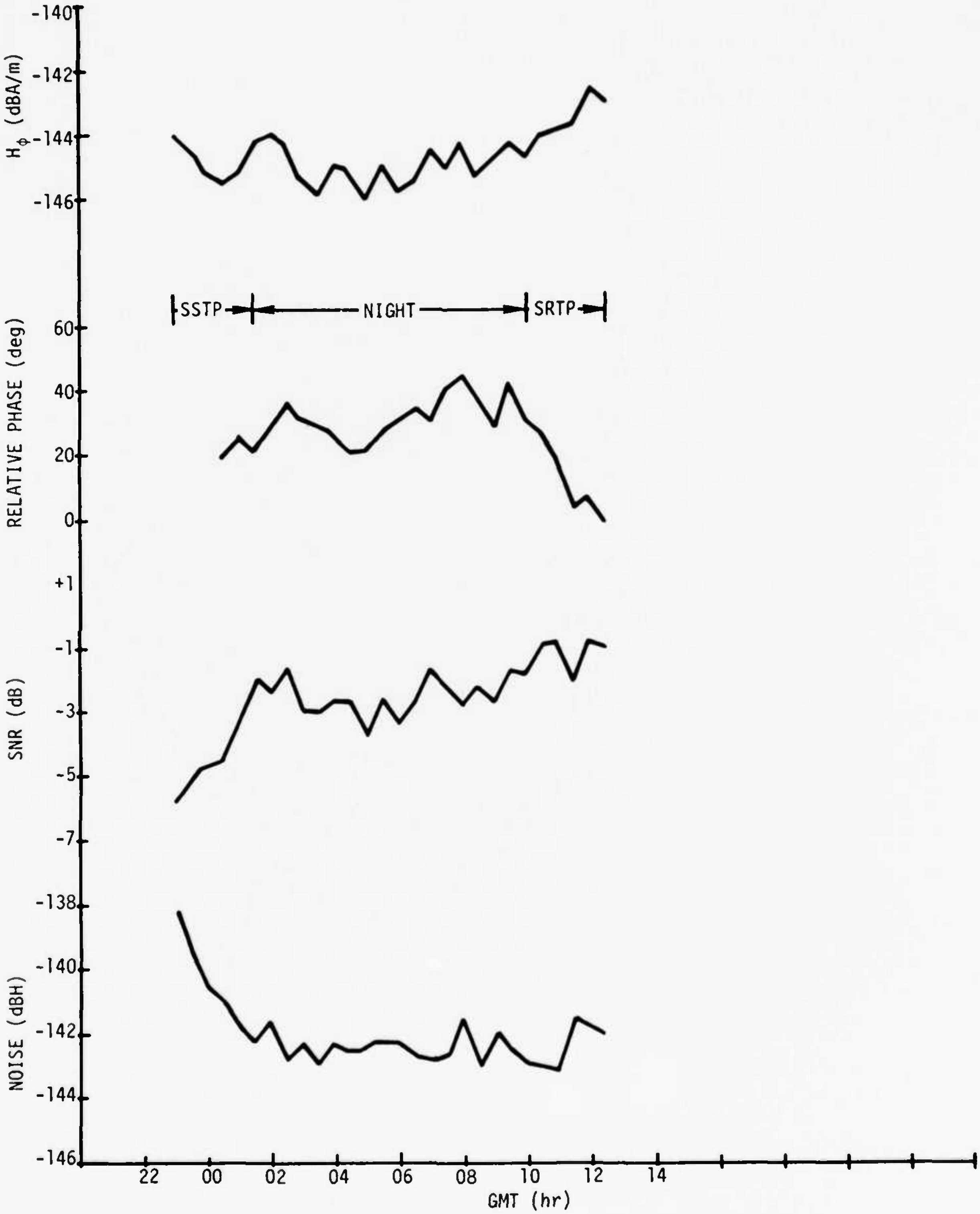


Figure B-45. Connecticut Data Versus GMT
(ψ = 291 deg), 22 March 1977

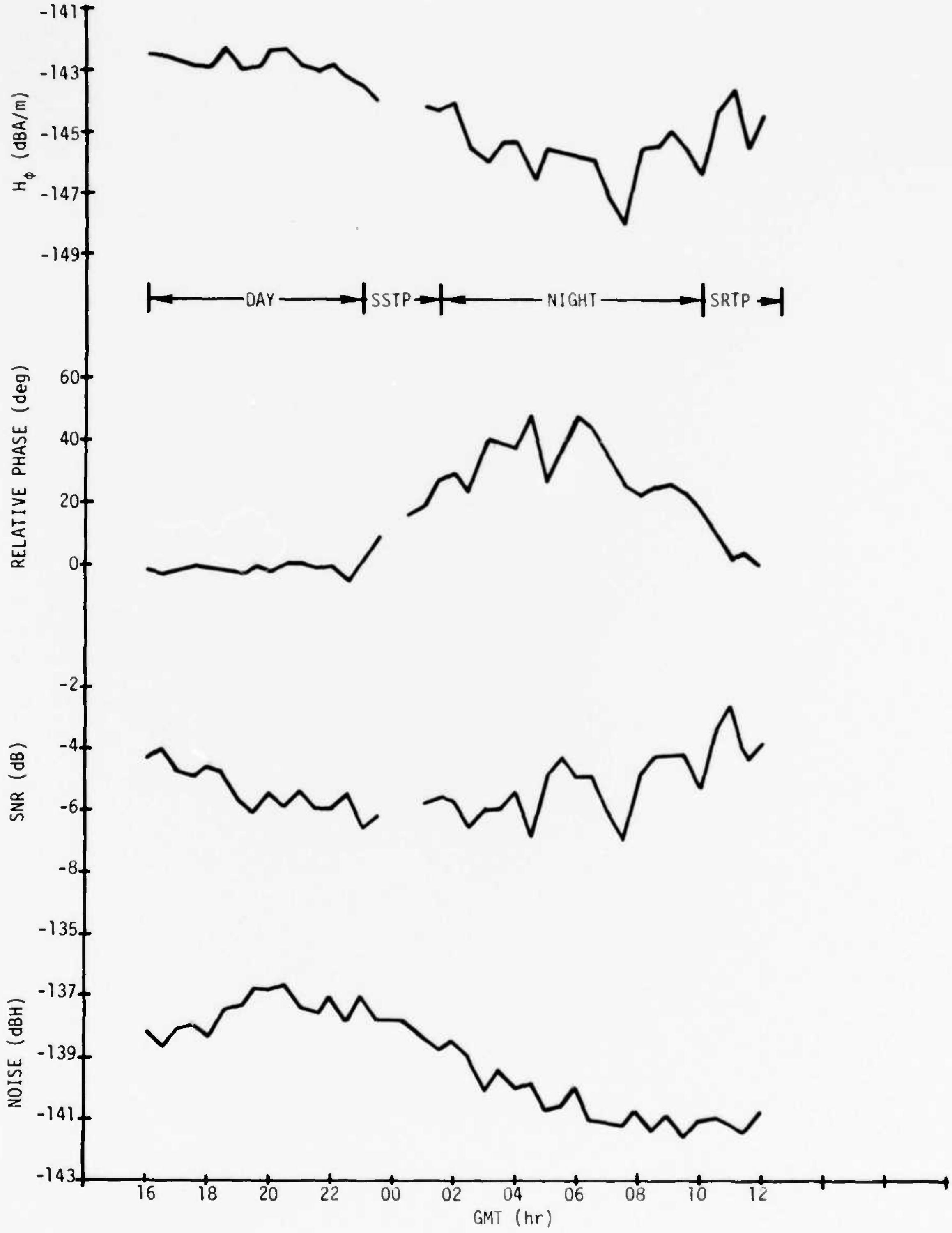


Figure B-46. Connecticut Data Versus GMT (ψ = 291 deg), 24 and 25 March 1977

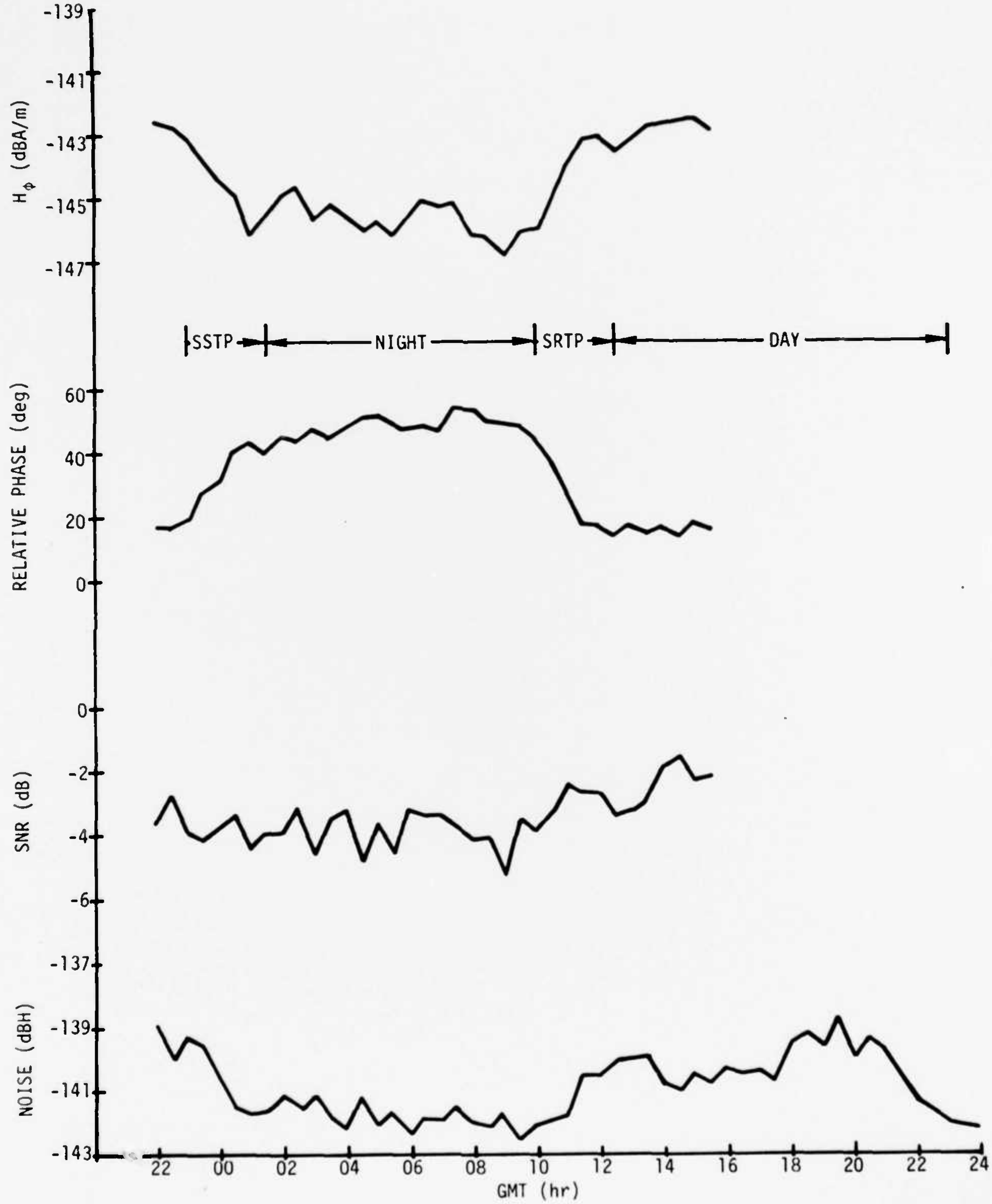


Figure B-47. Connecticut Data Versus GMT
(ψ = 291 deg), 26 March 1977

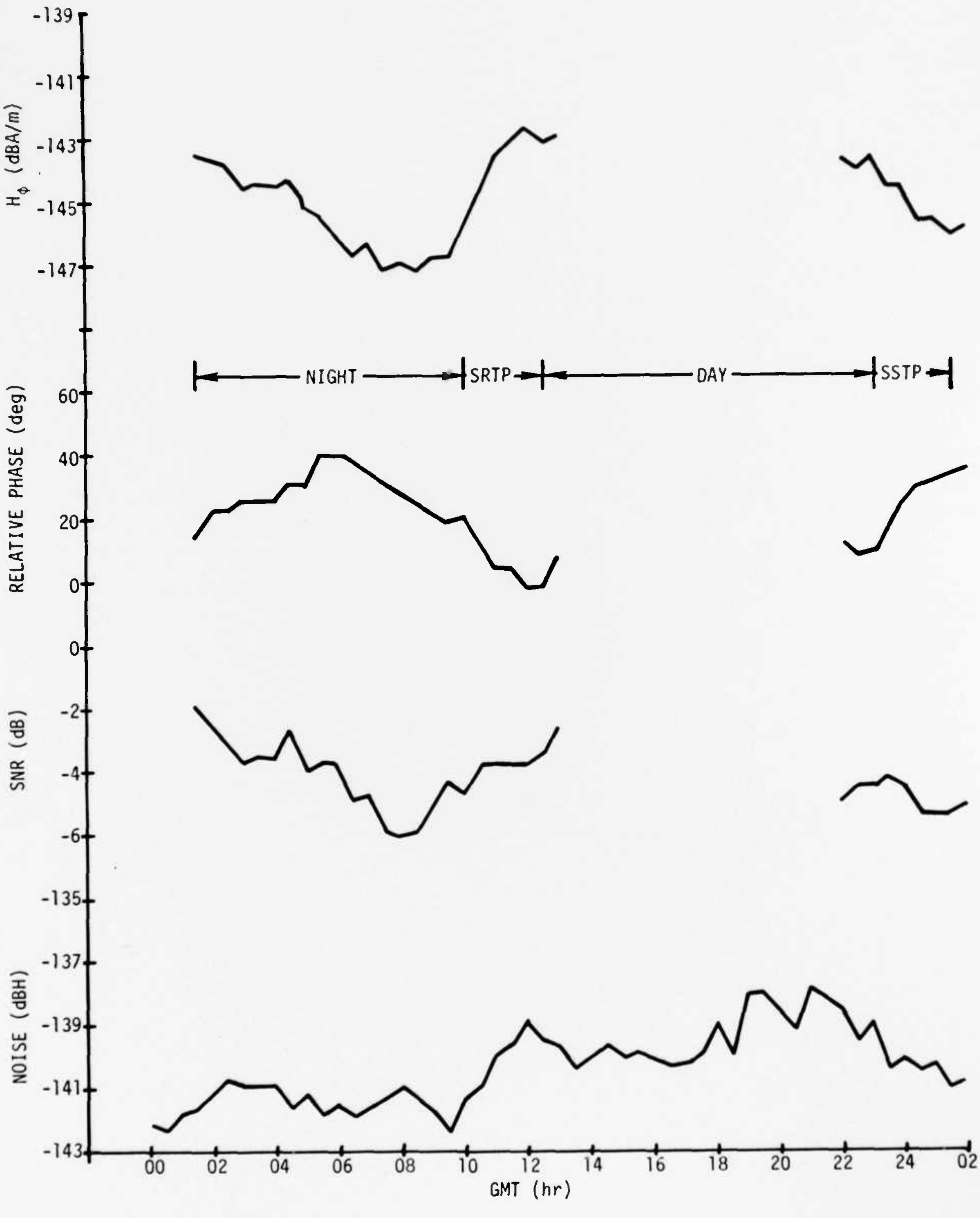


Figure B-48. Connecticut Data Versus GMT (ψ = 291 deg), 27 March 1977

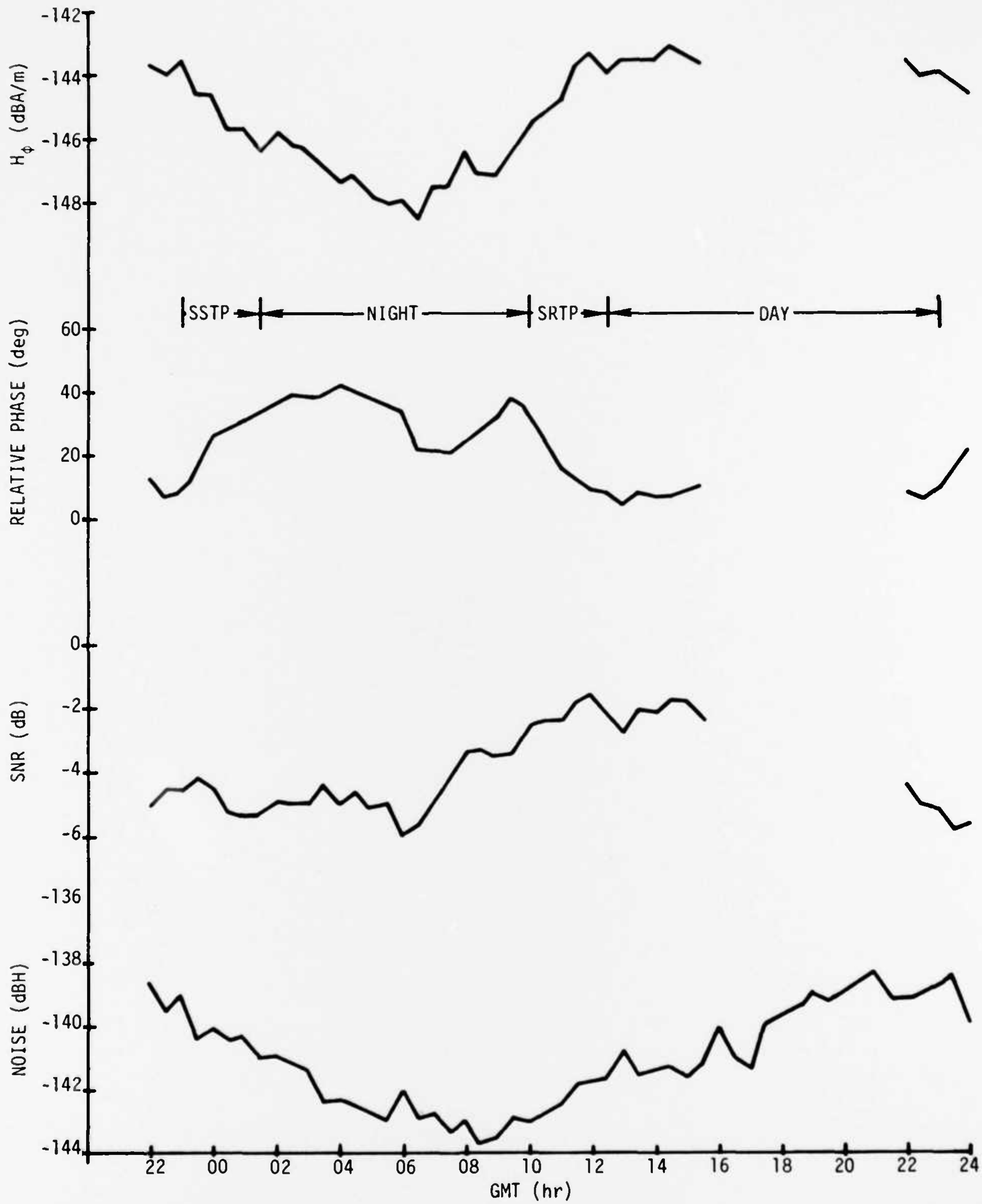


Figure B-49. Connecticut Data Versus GMT
(ψ = 291 deg), 28 March 1977

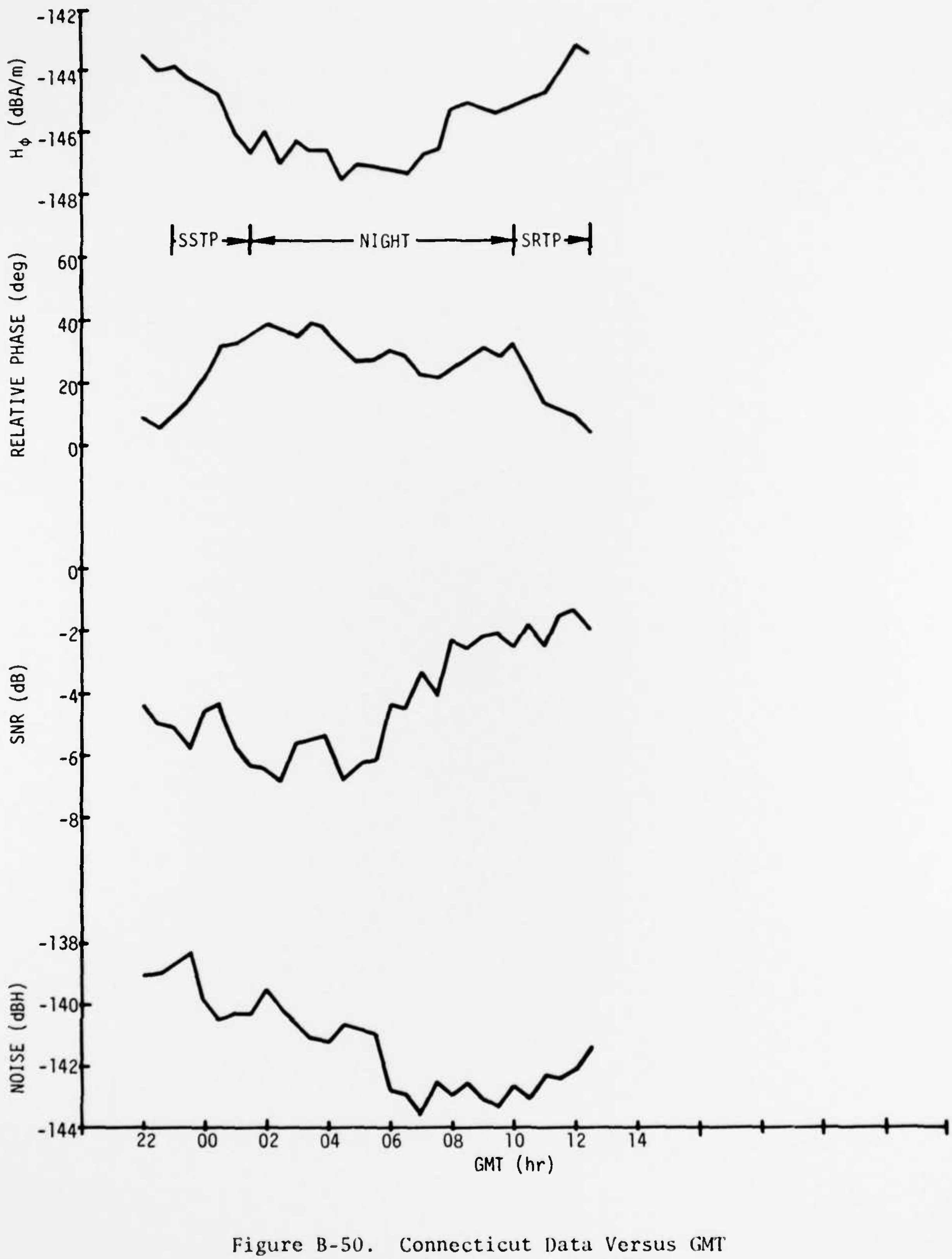


Figure B-50. Connecticut Data Versus GMT (ψ = 291 deg), 29 March 1977

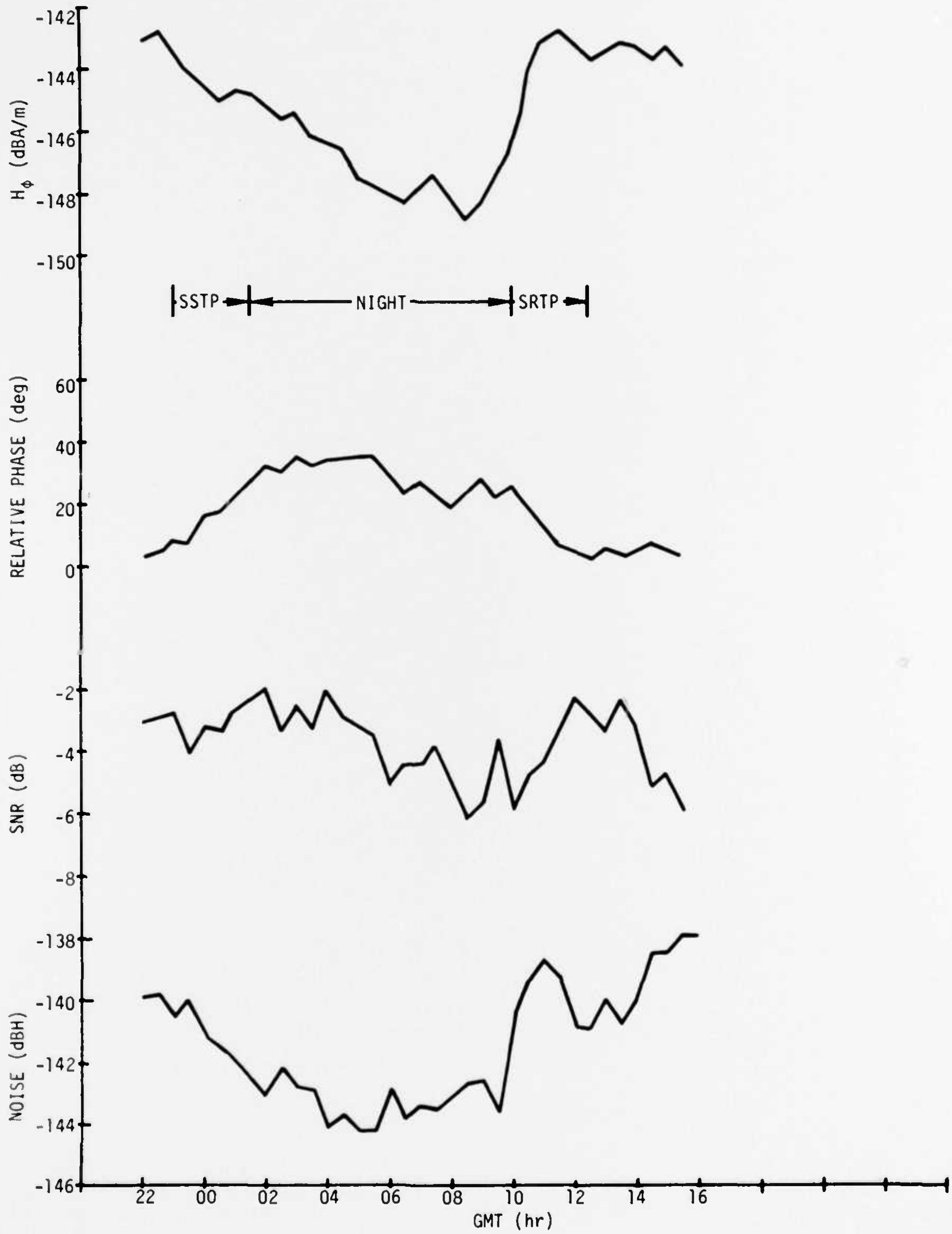


Figure B-51. Connecticut Data Versus GMT
(ψ = 291 deg), 30 March 1977

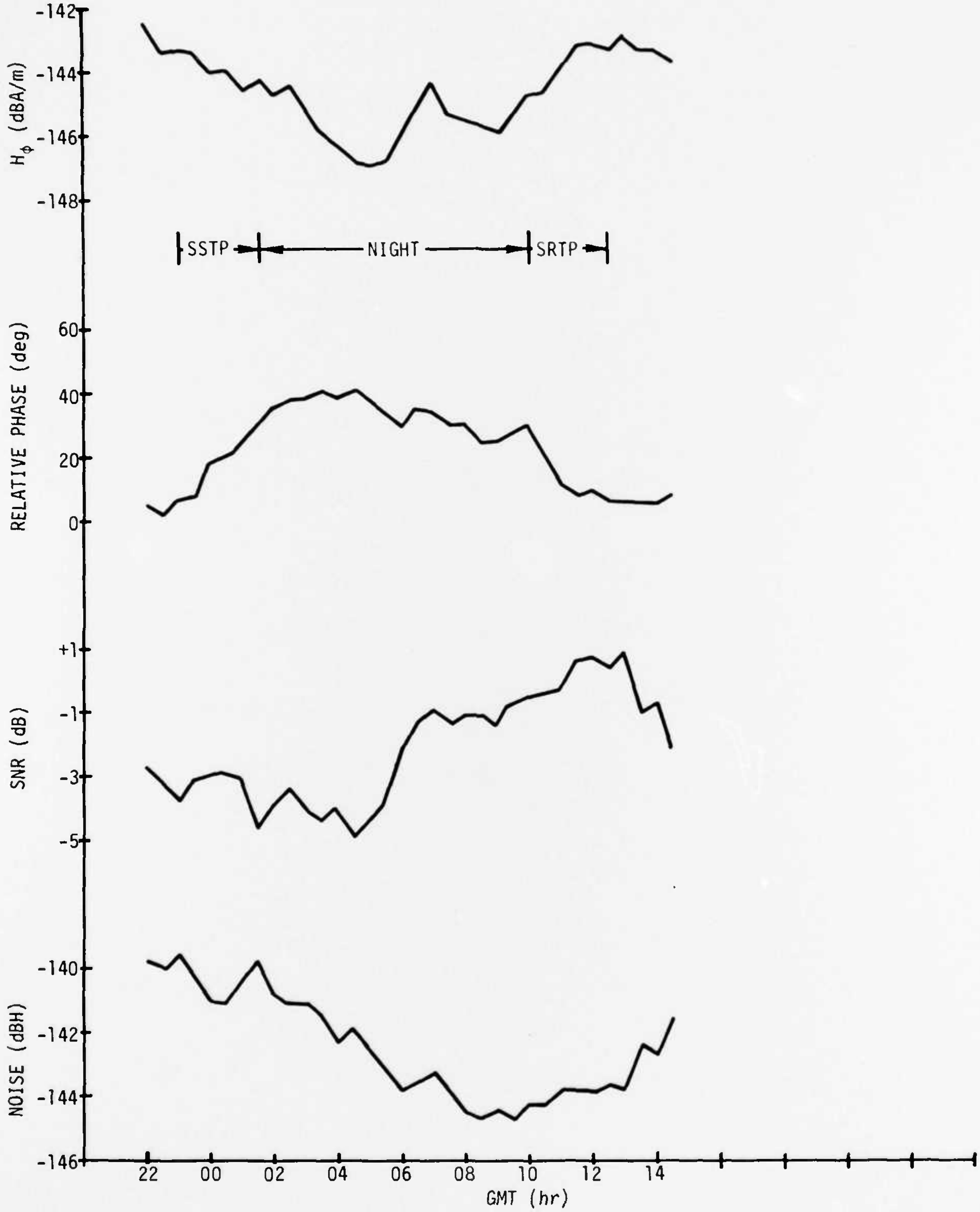


Figure B-52. Connecticut Data Versus GMT
(ψ = 291 deg), 31 March 1977

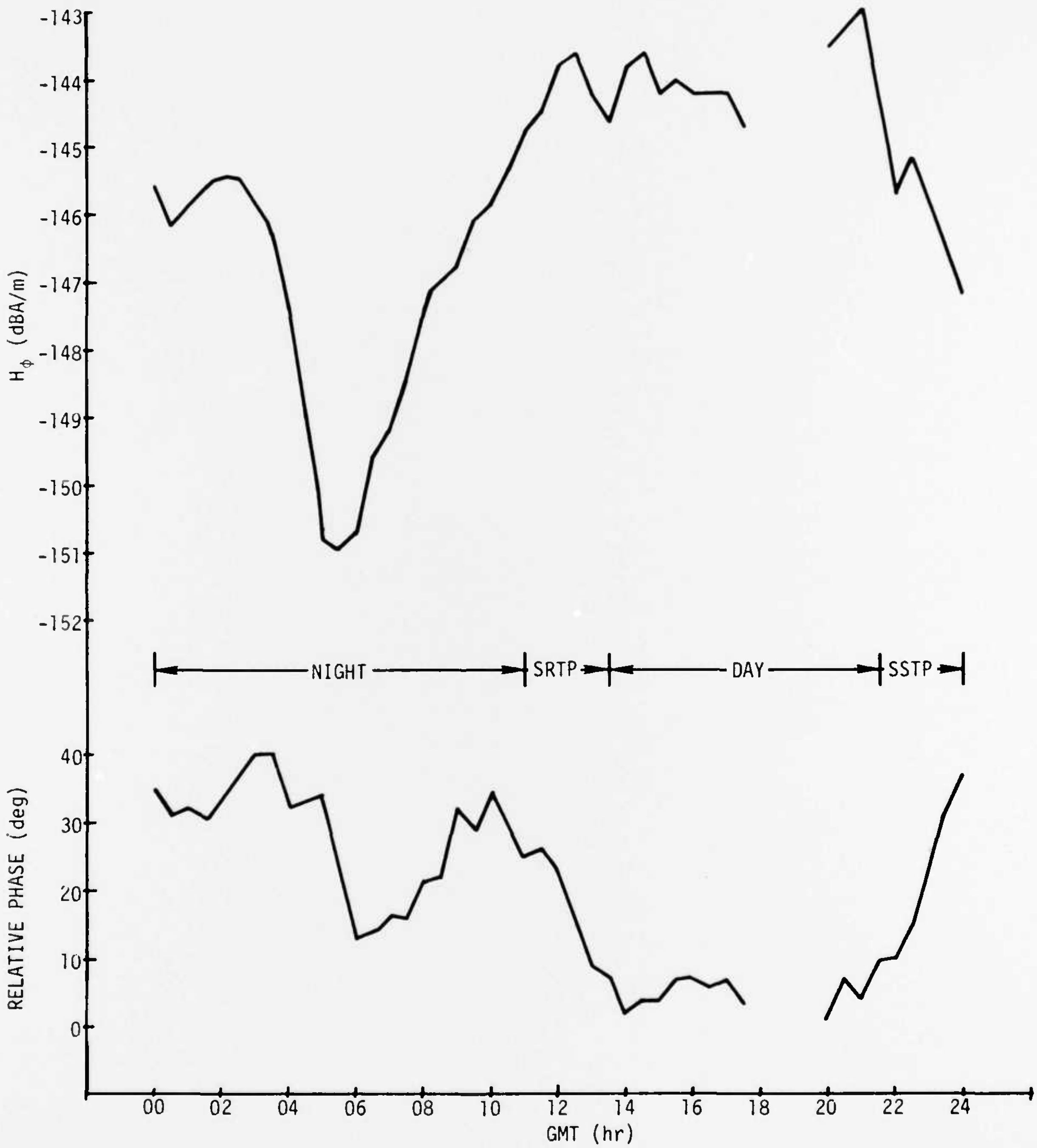


Figure B-53. Connecticut Field Strengths Versus GMT (Expanded Scale, ψ = 204 deg), 30 January 1977

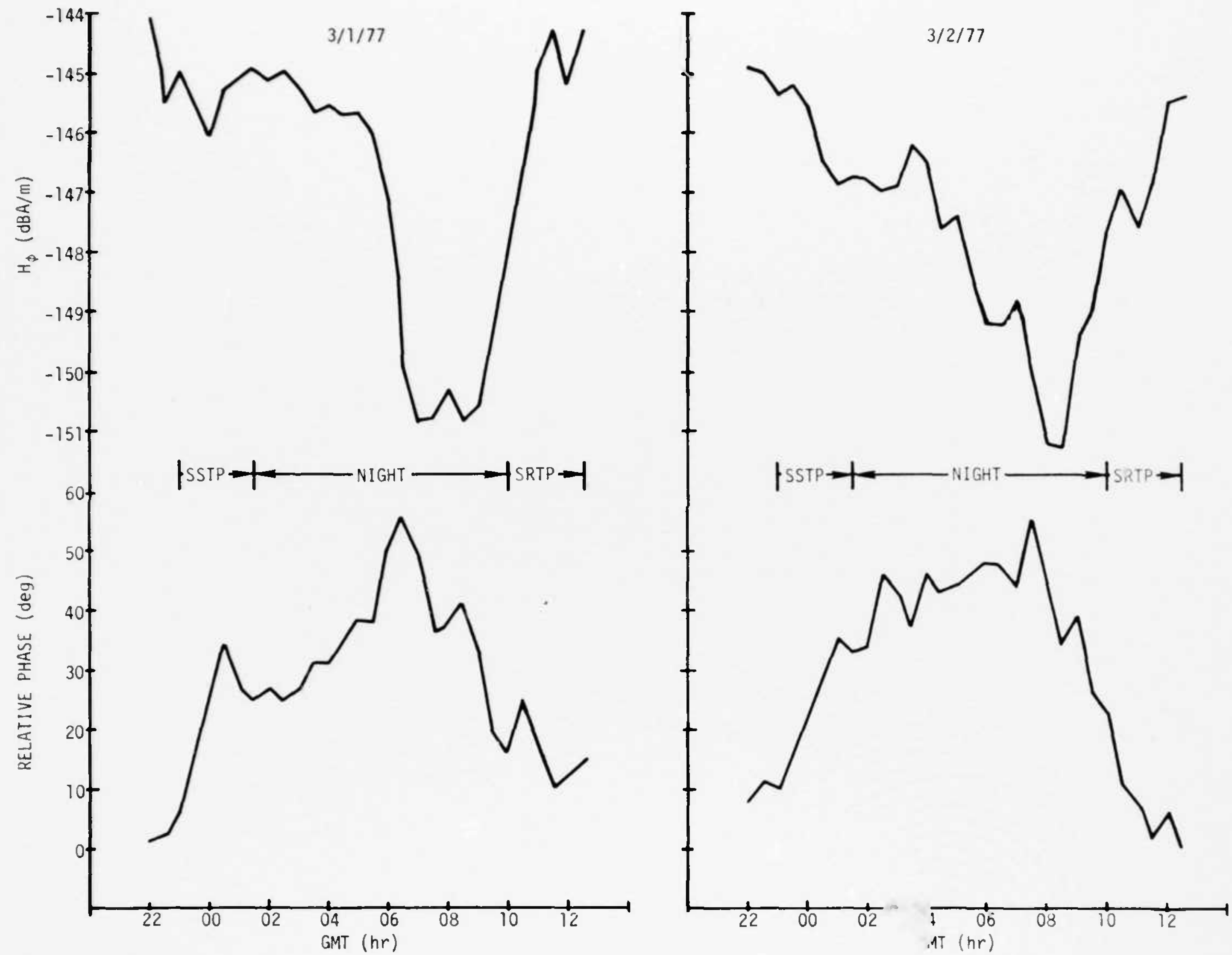


Figure B-54. Connecticut Field Strengths Versus GMT (Expanded Scale, ψ = 201 deg), 1 and 2 March 1977

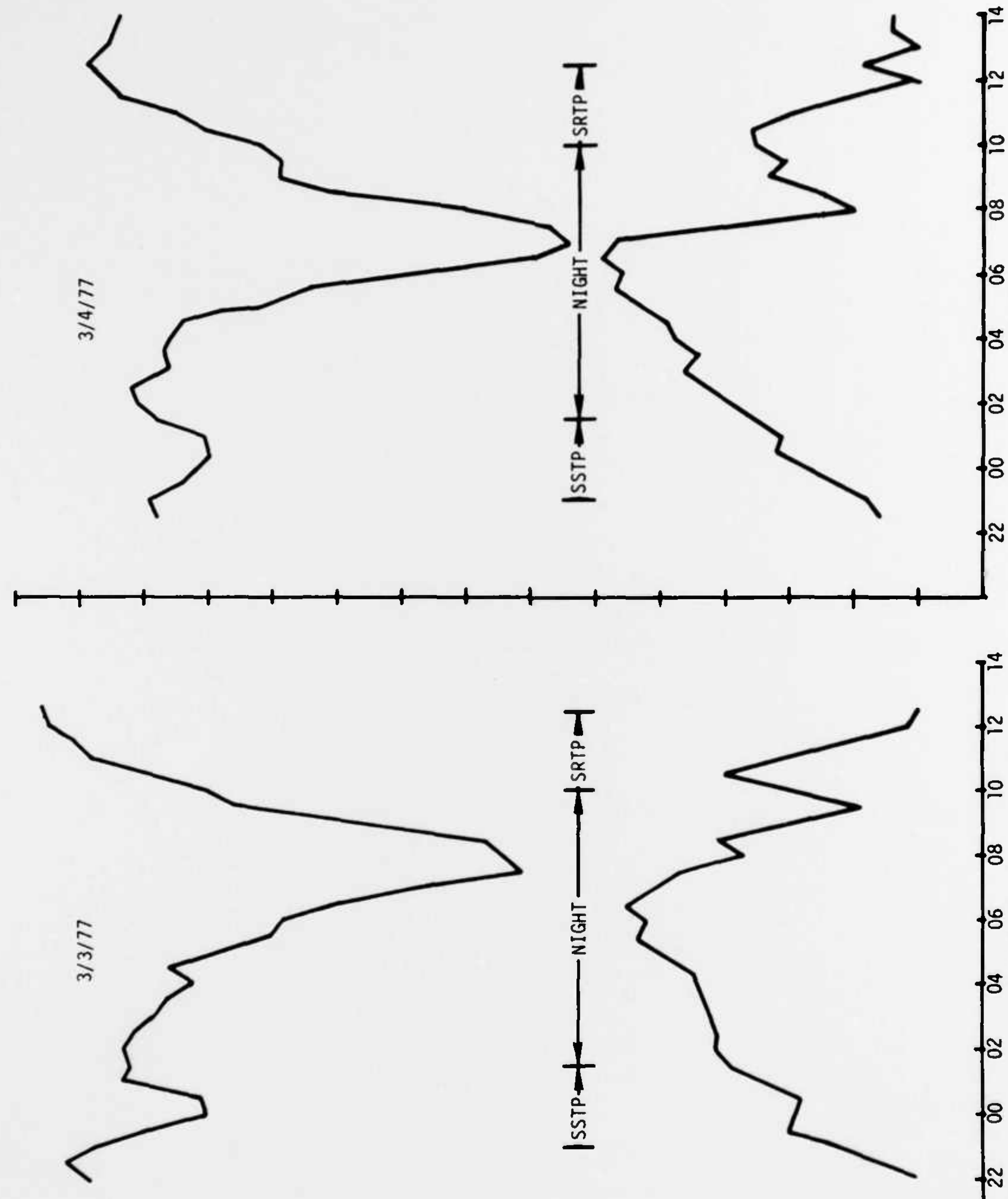


Figure B-55. Connecticut Field Strengths Versus GMT (Expanded Scale, ψ = 201 deg), 3 and 4 March 1977

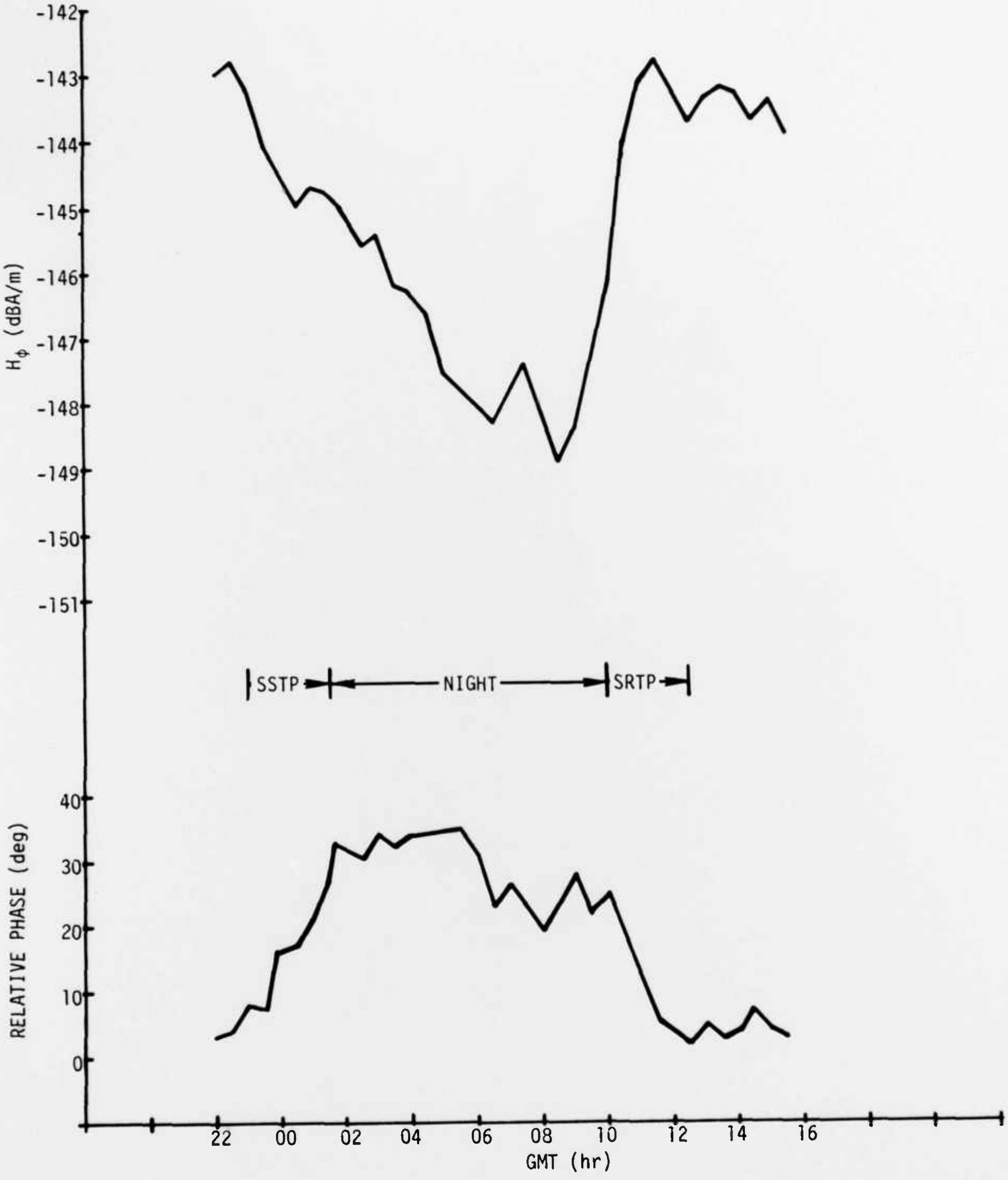


Figure B-56. Connecticut Field Strengths Versus GMT (Expanded Scale, ψ = 291 deg), 30 March 1977

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